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**APPLICATION FOR LETTERS PATENT**

**Inventors:**

Mark M. Goodman  
Timothy Shoup

**Amino Acid Analogs for**  
**Tumor Imaging**

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B. Kroge

Name of Applicant, Assignee or Registered Representative

B. Kroge

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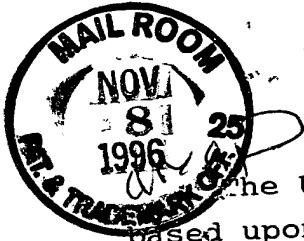
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Prepared by:

GREENLEE, WINNER AND SULLIVAN, P.C.  
5370 Manhattan Circle  
Suite 201  
Boulder, Colorado 80303  
(303) 499-8080  
FAX: (303) 499-8089

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## AMINO ACID ANALOGS FOR TUMOR IMAGING

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5 Field of the Invention

The invention includes novel chemical compounds having specific binding in a biological system and capable of being used for positron emission tomography (PET) and single photon emission (SPECT) imaging methods.

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Background of the Invention

The ability of analog compounds to bind to localized ligands within the body would make it possible, in principle, to utilize such compounds for *in situ* imaging of the ligands by PET, SPECT and similar imaging methods. In principle, nothing need be known about the nature of the ligand, as long as binding occurs, and such binding is specific for a class of cells, organs, tissues or receptors of interest. PET imaging is accomplished with the aid of tracer compounds labeled with a positron-emitting isotope (Goodman, M.M. Clinical Positron Emission Tomography, Mosby Yearbook, 1992, K.F. Hubner et al., Chapter 14). For most biological materials, suitable isotopes are few. The carbon isotope, [<sup>11</sup>C], has been used for PET, but its short half-life of 20.5 minutes limits its usefulness to compounds that can be synthesized and purified quickly, and to facilities that are proximate to a cyclotron where the precursor [<sup>11</sup>C] starting material is generated. Other isotopes have even shorter half-lives. [<sup>13</sup>N] has a half-life of 10 minutes and [<sup>15</sup>O] has an even shorter half-life of 2 minutes.

30 The emissions of both are more energetic than those of [<sup>11</sup>C]. Nevertheless, PET studies have been carried out with these isotopes (Hubner, K.F., in Clinical Positron Emission Tomography, Mosby Year Book, 1992, K. F. Hubner, et al.,

35 Chapter 2). A more useful isotope, [<sup>18</sup>F], has a half-life of 110 minutes. This allows sufficient time for incorporation into a radio-labeled tracer, for purification and for administration into a human or animal subject. In addition,

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facilities more remote from a cyclotron, up to about a 200  
5 mile radius, can make use of [<sup>18</sup>F] labeled compounds.  
Disadvantages of [<sup>18</sup>F] are the relative scarcity of fluorinated  
analogs that have functional equivalence to naturally-  
occurring biological materials, and the difficulty of  
10 designing methods of synthesis that efficiently utilize the  
starting material generated in the cyclotron. Such starting  
material can be either fluoride ion or fluorine gas. In the  
latter case only one fluorine atom of the bimolecular gas is  
actually a radionuclide, so the gas is designated <sup>18</sup>F-F.  
15 Reactions using <sup>18</sup>F-F as starting material therefore yield  
products having only one half the radionuclide abundance of  
reactions utilizing K<sup>18</sup>F as starting material. On the other  
hand, [<sup>18</sup>F] can be prepared in curie quantities as fluoride ion  
20 for incorporation into a radiopharmaceutical compound in high  
specific activity, theoretically 1.7 Ci/nmol using carrier-  
free nucleophilic substitution reactions. The energy emission  
of [<sup>18</sup>F] is 0.635 MeV, resulting in a relatively short, 2.4 mm  
average positron range in tissue, permitting high resolution  
PET images.

SPECT imaging employs isotope tracers that emit high  
energy photons ( $\gamma$ -emitters). The range of useful isotopes is  
greater than for PET, but SPECT provides lower three-  
dimensional resolution. Nevertheless, SPECT is widely used to  
25 obtain clinically significant information about analog  
binding, localization and clearance rates. A useful isotope  
for SPECT imaging is [<sup>123</sup>I], a  $\gamma$ -emitter with a 13.3 hour half  
life. Compounds labeled with [<sup>123</sup>I] can be shipped up to about  
1000 miles from the manufacturing site, or the isotope itself  
30 can be transported for on-site synthesis. Eighty-five percent  
of the isotope's emissions are 159 KeV photons, which is  
readily measured by SPECT instrumentation currently in use.

Use of [<sup>18</sup>F] labeled compounds in PET has been limited to  
a few analog compounds. Most notably, [<sup>18</sup>F]-fluorodeoxyglucose  
35 has been widely used in studies of glucose metabolism and  
localization of glucose uptake associated with brain activity.

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[<sup>18</sup>F]-L-fluorodopa and other dopamine receptor analogs have also been used in mapping dopamine receptor distribution.

5 Other halogen isotopes can serve for PET or SPECT imaging, or for conventional tracer labelling. These include <sup>75</sup>Br, <sup>76</sup>Br, <sup>77</sup>Br and <sup>82</sup>Br as having usable half-lives and emission characteristics. In general, the chemical means exist to substitute any halogen moiety for the described isotopes. Therefore, the biochemical or physiological activities of any halogenated homolog of the described 10 compounds are now available for use by those skilled in the art, including stable isotope halogen homologs. Astatine can be substituted for other halogen isotopes, [<sup>210</sup>At] for example emits alpha particles with a half-life of 8.3h. Other isotopes also emit alpha particles with reasonably useful 15 half-lives. At-substituted compounds are therefore useful for tumor therapy, where binding is sufficiently tumor-specific.

Numerous studies have demonstrated increased incorporation of carbohydrates and amino acids into malignant tumor cells. This accumulation is associated with accelerated 20 proliferation and protein synthesis of such cells. The glucose analog [<sup>18</sup>F]-2-fluoro-2-deoxy-D-glucose (2-FDG) has been used for distinguishing highly malignant brain tumors from normal brain tissue or benign growths (Dichiro, G. et al. 25 (1982) *Neurology (NY)* 32:1323-1329. However, fluorine-18 labeled 2-FDG is not the agent of choice for detecting low grade brain tumors because high uptake in normal tissue can mask the presence of a tumor. In addition, fluorine-18 labeled 2-FDG is not the ideal radiopharmaceutical for 30 distinguishing lung tumors from infectious tissue or detecting ovarian carcinoma because of high uptake of the 2-FDG radioactivity in infectious tissue and in the bladder, respectively. The naturally occurring amino acid methionine, labeled with carbon-11, has also been used to distinguish 35 malignant tissue from normal tissue. But it too has relatively high uptake in normal tissue. Moreover, the half-life of carbon-11 is only 20 minutes, therefore [<sup>11</sup>C]methionine can not be stored for a long period of time.

✓<sup>3</sup>

In an article titled, "1-Aminocyclobutane [<sup>11</sup>C] carboxylic Acid, a Potential Tumor-Seeking Agent," published in *J. Nucl. Med.* 20:1055-1061 (1979), L.C. Washburn et al. reported that the unnatural, alicyclic  $\alpha$ -amino acid, 1-aminocyclobutanecarboxylic acid (ACBC), labeled with carbon-14 or carbon-11, was incorporated preferentially by several tumor types in animals. ACBC has been shown to be a selective substrate for protein synthesis in metastatic lesions in the brain with little observable uptake in normal brain tissue.

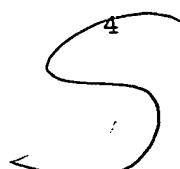
10 1-Amino-1-cyclobutane carboxylic acid is also a selective and potent ligand and antagonist for the excitatory amino acid receptor subtype N-methyl-D-aspartic acid (NMDA), specifically the strychnine-insensitive glycine recognition site. The NMDA receptor has been implicated in CNS disorders such as epilepsy, stroke, Huntington's disease, Alzheimer's disease 15 and schizophrenia.

20 Synthesis of ACBC has been carried out by the well-known Bücherer-Streker synthesis which is suitable for labeling with [<sup>11</sup>C] using [<sup>11</sup>C]-cyanide as precursor. (Washburn, L.C. et al., in Radiopharmaceuticals II: Proceedings 2nd International Symposium on Radiopharmaceuticals, March 19-22, 1979, Seattle, Washington.)

#### Summary of the Invention

25 The invention provides novel amino acid compounds of use in detecting and evaluating brain and body tumors. These compounds combine the advantageous properties of 1-amino-cycloalkyl-1-carboxylic acids, namely, their rapid uptake and prolonged retention in tumors with the properties of halogen substituents, including certain useful halogen isotopes 30 including fluorine-18, iodine-123, iodine-125, iodine-131, bromine-75, bromine-76, bromine-77, bromine-82, astatine-210, astatine-211, and other astatine isotopes.

35 In one aspect, the invention features amino acid compounds that have a high specificity for target sites when administered to a subject *in vivo*. Preferred amino acid compounds show a target to non-target ratio of at least 5:1,



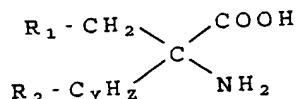
are stable in vivo and substantially localized to target within 1 hour after administration. An especially preferred amino acid compound is [<sup>18</sup>F]-1-amino-3-fluorocyclobutane-1-carboxylic acid (FACBC).

5 In another aspect, the invention features pharmaceutical compositions comprised of an  $\alpha$ -amino acid moiety attached to either a four, five, or a six member carbon-chain ring. In addition, the invention features analogs of  $\alpha$ -aminoisobutyric acid.

10 In a further aspect, the invention features amino acid compounds further comprising an imaging agent and uses for the compounds in detecting and/or monitoring tumors in a subject. In one embodiment, the amino acid compound imaging agent is administered in vivo and monitored using a means appropriate for the label. Preferred methods for detecting and/or monitoring an amino acid compound imaging agent in vivo include Positron Emission Tomography (PET) and Single Photon Emission Computer Tomography (SPECT).

15 Compounds of the invention include fluoro-, bromo- or iodo-substituted cyclobutyl, cyclopentyl, cyclohexyl amino acids as shown in Scheme 1 or singly unsaturated cyclic homologs thereof as shown in Scheme 2, or methylenyl fluoride or iodide-substituted analogs, as shown in Scheme 3, or fluoro- or iodo-substituted isobutyl amino acids as shown in Scheme 4. The substituted cyclic compounds of Schemes 1-3  
20 belong to the following generic formula:

~~10070X~~



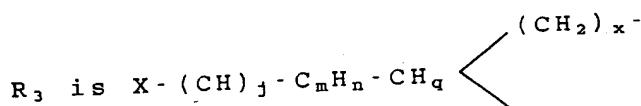
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where  $\text{R}_1$  is  $\text{X}$ ,  $\text{X}-\text{CH}=\text{CH}-$ , or  $\text{R}_3$

$\text{R}_2$  is  $\text{H}$ , or  $\text{R}_3$  if  $\text{R}_1$  is  $\text{R}_3$ ,

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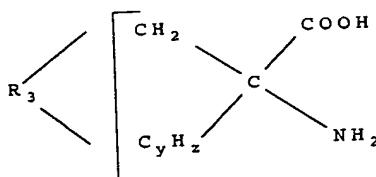
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such that

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is formed

where  $\text{x}$  is 0 or 1,

$\text{y}$  is 1 or 2,

$\text{z}$  is 1, 2, 3 or 4 and  $\text{z} > \text{y}$  if  $\text{y}$  is 2,

$\text{q}$  is 1 or 0 if  $\text{n}$  is 1 and  $\text{j}$  is 0,

$\text{n}$  is 1 or 2, but 0 if  $\text{m}$  is 0,

$\text{m}$  is 0 or 1,

$\text{j}$  is 0 or 1, and

$\text{X}$  is  $\text{F}$ ,  $^{18}\text{F}$ ,  $\text{I}$ ,  $^{123}\text{I}$ ,  $^{125}\text{I}$ ,  $^{131}\text{I}$ ,  $\text{Br}$ ,  $^{75}\text{Br}$ ,  $^{76}\text{Br}$ ,  $^{77}\text{Br}$ ,  $^{82}\text{Br}$ , or  $\text{At}$

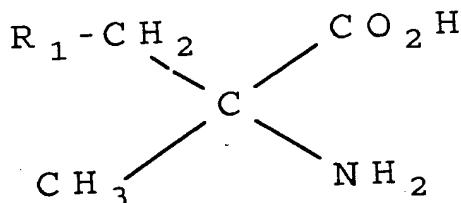
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Non-cyclic, but sterically similar compounds of the invention have the following generic formula, as shown in Scheme 4.

Scheme 4.

~~10072X~~



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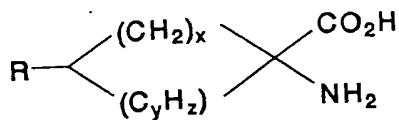
where  $R_1$  is X or X-CH=CH-

and X is I,  $^{131}I$ ,  $^{123}I$ ,  $^{125}I$ , F,  $^{18}F$ , Br,  $^{75}Br$ ,  $^{76}Br$ ,  $^{77}Br$ ,  $^{82}Br$ , or At

5           The compounds of the invention are useful as tumor-binding agents and as NMDA receptor-binding ligands, and in radio-isotopic form are especially useful as tracer compounds for tumor imaging techniques, including PET and SPECT imaging. 10 Where X is At, the compounds have utility for radio-therapy. In order to synthesize the compounds to maximize a useful lifetime for short-lived isotopes, and to maximize yield and purity, specialized, non-standard routes had to be devised, as described.

15           The compounds of the invention can be labeled with Technetium. Technetium-99m is known to be a useful radionuclide for SPECT imaging. The cyclic amino acids of the invention are joined to a Tc-99m metal cluster through a 4-6 carbon chain which can be saturated or possess a double or triple bond. The Tc-99m metal cluster can be, for example, an alkylthiolato complex, a cytectrene or a hydrazino nicotinamide complex (HYNIC). The linking structure can be  $R_4$  (replacing  $R_3$ ) in the foregoing diagram where  $R_4$  is  $Z-(CH_2)_a-$  20  $CH_b-CH_b-CH<$  where a is 1, 2 or 3, b is 0, 1 or 2, and Z is an alkylthiolato-Te complex, a Tc-cytectrene or a Tc-HYNIC 25 complex.

SCHEME 1



*T0090X*

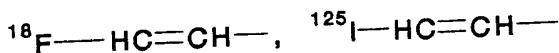
R =  $^{75}\text{Br}$ ,  $^{76}\text{Br}$ ,  $^{77}\text{Br}$ ,  $^{82}\text{Br}$

$^{131}\text{I}$ ,  $^{123}\text{I}$ ,  $^{125}\text{I}$ ,  $^{18}\text{F}$ ,  $^{18}\text{FCH}_2$ ,  $^{210}\text{At}$

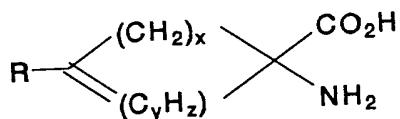
x = 1 or 2

y = 1 or 2

z = 2 or 4



SCHEME 2



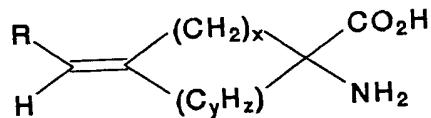
R =  $^{75}\text{Br}$ ,  $^{76}\text{Br}$ ,  $^{77}\text{Br}$ ,  $^{82}\text{Br}$ ,  
 $^{123}\text{I}$ ,  $^{125}\text{I}$ ,  $^{131}\text{I}$ ,  $^{210}\text{At}$

x = 1 or 2

y = 1 or 2

z = 1 or 3

SCHEME 3



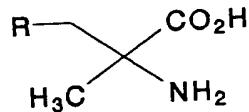
R =  $^{123}\text{I}$ ,  $^{125}\text{I}$ ,  $^{131}\text{I}$ ,  $^{18}\text{F}$ ,  
 $^{75}\text{Br}$ ,  $^{76}\text{Br}$ ,  $^{77}\text{Br}$ ,  $^{82}\text{Br}$ ,  $^{210}\text{At}$

x = 1 or 2

y = 1 or 2

z = 2 or 4

SCHEME 4



R =  $^{18}\text{F}$ , X-HC=CH-

X =  $^{123}\text{I}$ ,  $^{125}\text{I}$ ,  $^{131}\text{I}$ ,  $^{18}\text{F}$ ,  $^{75}\text{Br}$ ,  
 $^{76}\text{Br}$ ,  $^{77}\text{Br}$ ,  $^{82}\text{Br}$ ,  $^{210}\text{At}$

Detailed Description of the Invention

Compounds of the invention provide substantially improved PET imaging for areas of the body having malignant tumors, especially tumors of the brain. All the available positron-emitting isotopes which could be incorporated into a biologically-active compound have short half-lives. The practical utility of such labeled compounds is therefore dependent on how rapidly the labeled compound can be synthesized, the synthetic yield and the radiochemical purity of the final product. Even the shipping time from the isotope source, a cyclotron facility, to the hospital or laboratory where PET imaging is to take place, is limited. A rough calculation of the useful distance is about two miles per minute of half-life. Thus [<sup>11</sup>C], with a half-life of 20.5m is restricted to about a 40 mile radius from a source whereas compounds labeled with [<sup>18</sup>F] can be used within about a 200 mile radius. Further requirements of an [<sup>18</sup>F]-labeled compound are that it have the binding specificity for the receptor or target molecule it is intended to bind, that non-specific binding to other targets be sufficiently low to permit distinguishing between target and non-target binding, and that the label be stable under conditions of the test to avoid exchange with other substances in the test environment. More particularly, compounds of the invention must display adequate binding to the desired target while failing to bind to any comparable degree with other tissues or cells. Furthermore, the fluorine, iodine or bromine label must not be labile or unstable such that significant amounts appear in, e.g. bone or thyroid, or other non-target tissue respectively.

A partial solution to the stringent requirements for PET imaging is to employ  $\gamma$ -emitting isotopes in SPECT imaging. [<sup>123</sup>I] is a commonly used isotopic marker for SPECT, having a half-life of 13 hours for a useful range of over 1000 miles from the site of synthesis. Compounds of the invention can be rapidly and efficiently labeled with [<sup>123</sup>I] for use in SPECT analysis as an alternative to PET imaging. Furthermore, because of the fact that the same compound can be labeled with

either isotope, it is possible for the first time to compare the results obtained by PET and SPECT using the same tracer.

In vivo distribution of a compound of the invention, [<sup>18</sup>F]-1-amino-3-fluoro-cyclobutane-1-carboxylic acid (FACBC) was measured in rats having an implanted gliosarcoma.

Accumulation in various tissue was measured at 5 min and 60 min post-administration. The compound was immediately seen to be preferentially associated with tumor tissue as early as 5 minutes post administration, with relatively little uptake in other tissues. After 60 minutes, an increased level of tumor uptake relative to non-malignant brain tissue was observed, with very little additional uptake in other tissues. Uptake by bone was essentially constant over the 60 minutes of exposure, indicating stability of the 2-cyclobutyl group to significant *in vivo* defluorination. The tumor uptake exhibited a maximum at 60 minutes of 1.72% of total injected dose/gram of tissue, with a maximum ratio of tumor to brain of 6.61, compared to 5.58 at 5 minutes. By contrast, [<sup>18</sup>F] fluorodeoxyglycose (FDG) showed rapid accumulation but poor discrimination between tumor and brain, the dose/gram ratio of tumor uptake to brain uptake being 0.84 at 60 min. The results with [<sup>18</sup>F]FACBC indicate that the compound is a valuable imaging agent for diagnosis, management and imaging of malignant tumors, using PET imaging.

The specificity of tumor binding also provides utility for I-substituted compounds of the invention. Such compounds can be labeled with short-lived <sup>123</sup>I for SPECT imaging or with longer-lived <sup>125</sup>I for longer-term studies such as monitoring a course of therapy. Other iodine and bromine isotopes can be substituted for those exemplified.

The compounds of the invention therefore provide improved methods for tumor imaging using PET and SPECT. The methods entail administering to a subject (which can be human or animal, for experimental and/or diagnostic purposes) an image-generating amount of a compound of the invention, labeled with the appropriate isotope and then measuring the distribution of the compound by PET if [<sup>18</sup>F] or other positron emitter is

employed, or SPECT if [<sup>123</sup>I] or other gamma emitter is employed. An image-generating amount is that amount which is employed. An image-generating amount is that amount which is at least able to provide an image in a PET or SPECT scanner, taking into account the scanner's detection sensitivity and noise level, the age of the isotope, the body size of the subject and route of administration, all such variables being exemplary of those known and accounted for by calculations and measurements known to those skilled in the art without resort to undue experimentation.

It will be understood that compounds of the invention can be labeled with an isotope of any atom or combination of atoms in the structure. While [<sup>18</sup>F], [<sup>123</sup>I] and [<sup>125</sup>I] have been emphasized herein as being particularly useful for PET, SPECT and tracer analysis, other uses are contemplated including those flowing from physiological or pharmacological properties of stable isotope homologs and will be apparent to those skilled in the art.

A high degree of tumor specific binding has been observed for compounds of the invention, in human patients as well as in experimental animals. The high specificity has inspired the use of At-substituted compounds of the invention for therapeutic use. At isotopes are emitters of alpha particles, where short range is useful for tumor radiotherapy.

The invention also provides for technetium (Tc) labeling via Tc adducts. Isotopes of Tc, notably Tc<sup>99m</sup>, have been used for tumor imaging. The present invention provides Tc-complexed adducts of compounds of the invention, which are useful for tumor imaging. The adducts are Tc-coordination complexes joined to the cyclic amino acid by a 4-6 carbon chain which can be saturated or possess a double or triple bond. Where a double bond is present, either E (trans) or Z (cis) isomers can be synthesized, and either isomer can be employed. Synthesis is described for incorporating the <sup>99m</sup>Tc isotope as a last step, to maximize the useful life of the isotope.

Example 1:

Synthesis of [18F]-1-amino-3-fluoro-cyclobutane-1-carboxylic acid (FACBC)

As will be described in detail hereinafter, the compound  
can be prepared by the steps represented in Steps 1-11.

The following methods were employed in procedures

reported herein.  $[^{18}\text{F}]$ -Fluoride was produced from a Seimens cyclotron using the  $^{18}\text{O}(\text{p},\text{n})^{18}\text{F}$  reaction with 11 MeV protons on 95% enriched  $[^{18}\text{O}]$  water. All solvents and chemicals were

analytical grade and were used without further purification.

Melting points of compounds were determined in capillary tubes by using a Buchi SP apparatus. Thin-layer chromatographic analysis (TLC) was performed by using 250-mm thick layers of

silica gel G PF-254 coated on aluminum (obtained from Analtech, Inc.). Column chromatography was performed by using

60-200 mesh silica gel (Aldrich Co.). Infrared spectra (IR) were recorded on a Beckman 18A spectrophotometer with NaCl

plates. Proton nuclear magnetic resonance spectra ( $^1\text{H}$  NMR) were obtained at 300 MHz with a Nicolet high-resolution

instrument.

Synthesis of 1-Chloro-2-benzyloxy-3-bromopropane 3:

A mixture of benzyl bromide 1 (46.2 g, 0.27 mol), epichlorohydrin 2 (25 g, 0.27 mol), and 0.045 g of mercurous chloride was heated for 12 hr at 150° C (Step 1).

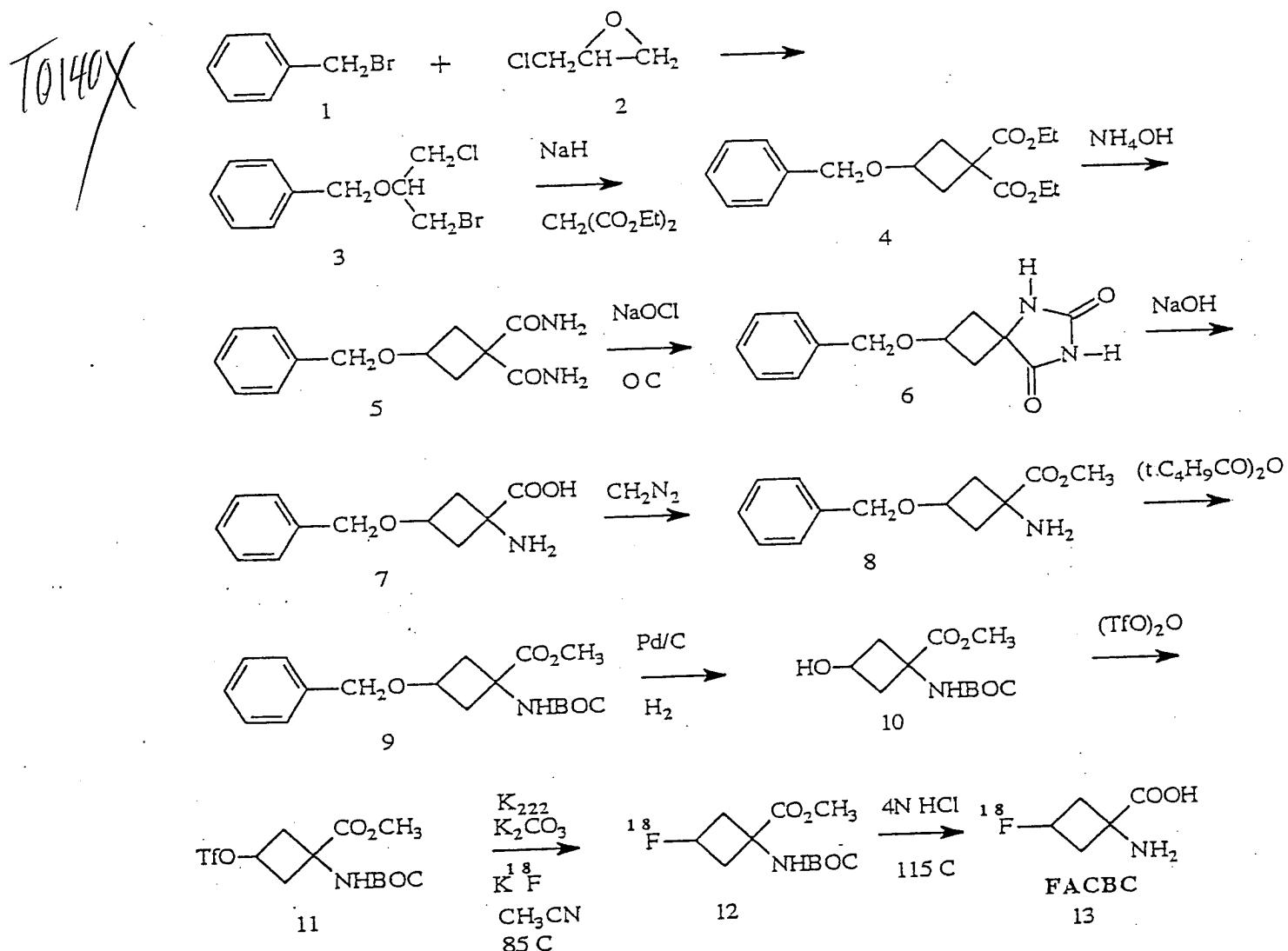
Distillation through a 12-in Vigreux column yielded 55.8g (79%) of 1-chloro-2-benzyloxy-3-bromopropane, 3 bp 142-145 (0.3 mm);  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  3.34-3.9 (m, 4H,  $\text{CH}_2$ ), 4.58 (s, 2H, O- $\text{CH}_2$ ), 7.26 (s, 5H, phenyl).

Synthesis of Diethyl-3-benzyloxy cyclobutane-1-dicarboxylate

4:

To a stirred slurry of 4.6g (0.19 mol) sodium hydride in 115 mL of dry dioxane was added dropwise 30.4 (0.10 mol) of diethyl malonate over a 30 min period. After this addition was complete, 50.0g (0.19 mol) of 1-chloro-2-benzyloxy-3-bromopropane 3 was added dropwise in 30 min (Step 2). The mixture was heated at reflux for 44 hr, cooled to room

Synthesis of FACBC



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temperature, and 4.6g (0.19 mol) of sodium hydride in 50 mL of dioxane was added in portions. The mixture was heated at reflux for an additional 120 hr. The solvent was partially removed under reduced pressure and the mixture was treated with 100 mL of water. The organic layer was extracted into ether. The ether extracts were dried and concentrated and the residue was distilled under reduced pressure. Distillation through a 12-in Vigreux column yielded 49.0g (85%) of diethyl 3-benzyloxycyclobutane-1, 1-dicarboxylate **4** bp 174-176° C (0.9 mm); <sup>1</sup>H NMR(CDCl<sub>3</sub>) δ 1.23 (t, J=7Hz, 6H, CH<sub>3</sub>), 4.0-4.7 (m, 1H OCH), 4.34 (s, 2H OCH<sub>2</sub>), 4.13 (q, J=7Hz, 4H, OCOCH<sub>2</sub>), 7.23 (s, 5H, phenyl).

Synthesis of 3-benzyloxycyclobutane-1,1-dicarboxamine **5**:

Diethyl 3-benzyloxycyclobutane-1,1-dicarboxylate **4** (20g. 65mmol) was stirred with concentrated aqueous ammonia (250 mL) for four days at room temperature (Step 3). The diamide **5** was collected by filtration and washed with water followed by ethyl acetate. The yield was 8.1g (50%). <sup>1</sup>H NMR (d6-DMSO) δ 2.2 (m, 2H, CH<sub>2</sub>), 2.5 (m, 2H, CH<sub>2</sub>), 3.8 (q, J=7.2Hz 1H OCH), 4.3 (s, 2H, OCH<sub>2</sub>), 7.0 (m, 4H, NH<sub>2</sub>), 7.23 (s, 5H, phenyl).

Synthesis of cis/trans 5-(3-benzyloxycyclobutane)hydantoin **6**:

3-Benzylloxycyclobutane-1, 1-dicarboxamine, **5** (2.0 g, 8 mmol) was stirred in 150 mL of dilute sodium hypochlorite (Aldrich product/water 1 to 2) at 0-5° C for four hrs (Step 4). The reaction mixture stood overnight at room temperature. Unreacted diamide was recovered by filtration. The solution was neutralized to pH 5 with concentrated hydrochloric acid and evaporated to dryness *in vacuo*. The residue was extracted with 50 mL of hot methanol, filtered, and washed with 50 mL of hot methanol. The methanol solutions were combined and evaporated. Yield of the mixture of *cis* and *trans* hydantoins **6** was 1.4 g(70%).

Synthesis of 1-amino-3-benzyloxycyclobutane-1-carboxylic acid **7**:

The hydantoin **6** (1.0 g, 4.1 mmol) was hydrolyzed by refluxing with 10 mL of a barium hydroxide solution (saturated at room temperature) for 16 hr (Step 5). The solution was neutralized to pH 6 with 2 M sulfuric acid and evaporated to

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dryness *in vacuo*. The residue was extracted with 50 mL of hot methanol, filtered, and washed with 50 mL of hot methanol. The methanol solutions were combined and evaporated. Yield of the 1-amino-3-benzyloxycyclobutane-1-carboxylic acid 7 was 5 0.69 g (76%).  $^1\text{H}$  NMR ( $\text{d}_4$ -methanol)  $\delta$  2.2-2.9 (m, 4H,  $\text{CH}_2$ ), 4.3 (t,  $J=6.9$  Hz, 1H, OCH), 4.5 (s, 2H,  $\text{OCH}_2$ ), 7.23 (br s, 5H, phenyl).

Synthesis of 1-t-butylcarbamate-3-benzyloxycyclobutane-1-carboxylic acid 8:

10 A solution of the amino acid 7 (0.5 g, 2.3 mmol) in 10 mL of a mixture of methanol/triethylamine (90:10) was treated with 1.0g (4.6 mmol) of di-tert-butyl dicarbonate (Step 6). The mixture was heated at 50-60°C for 10 min and then the solvent was removed by rotoevaporation. The crude product was 15 stirred in 5 mL of dilute HCl (pH=2) at 0°C for 10 min. The mixture was extracted with  $\text{CH}_2\text{Cl}_2$  (2x10 mL), the combined extract dried, and the solvent was removed. The crude oil was chromatographed on silica gel using methylene chloride/methanol (9 to 1) with 0.1% formic acid. The product 20 8 (0.55 g, 78%) showed a single spot on TLC ( $R_f=0.59$ ) with the same solvent system; visualization was with  $\text{MoO} \cdot \text{H}_3\text{PO}_4$ .

Synthesis of 1-t-butylcarbamate-3-benzyloxycyclobutane-1-carboxylic-methyl ester 9:

25 To a slurry of 1-methyl-3-nitro-1-nitrosoguanidine (150 mg) in 8 mL of ether at 0-5°C was added a 40% solution of potassium hydroxide dropwise. The resultant diazomethane ether solution was added to 0.15 g (0.50 mmol) of 1-t-butyl carbamate-3-benzyloxycyclobutane-1-carboxylic methyl ester acid in 3 mL of ether (Step 7) and the mixture was stirred at 30 room temperature for 15 min. The mixture was washed with water (10mL) and the ether evaporated. The crude residue was chromatographed on silica gel using ethyl acetate/hexane (1 to 9). Yield: 0.13g (82%);  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  1.35 (s, 9H,  $\text{CH}_3$ ), 2.27-2.88 (m, 4H,  $\text{CH}_2$ ), 3.72 (s, 3H,  $\text{CH}_3$ ), 4.18 (m, 1H, CHO), 4.42 (s, 2H,  $\text{OCH}_2$ ), 7.23 (br s, 5H, phenyl).

✓ Synthesis of 1-t-butylcarbamate-3-hydroxy-cyclobutane-1-carboxylic acid methyl ester 10:

A solution of 0.10g (0.3 mmol) of the protected amino acid benzyl ether **9** in 5 mL of methanol was mixed with a suspension of 25 mg of 10% palladium on charcoal in 5 mL of methanol (Step 8). The mixture was stirred under a positive pressure of hydrogen (balloon) for 16 hr. The catalyst was filtered off and the solvent was evaporated. The crude residue was chromatographed on silica gel using methylene chloride/methanol (9 to 1). The product **10** (74 mg 89%) showed a single spot on TLC ( $R_f=0.81$ ) with the same solvent system; visualization was with  $\text{MoO}\cdot\text{H}_3\text{PO}_4$ .

✓ Synthesis of 1-t-butylcarbamate-3-trifluoromethane sulfonyxycyclobutane-1-carboxylic acid methyl ester 11:

The alcohol **10** (25 mg, 0.10 mmol) was dissolved in 10 mL of dry methylene chloride and pyridine (12 $\mu\text{L}$ ) by stirring under  $\text{N}_2$ . The solution was cooled to 0-5°C and 12 $\mu\text{L}$  of trifluoromethane sulfonic anhydride was added (Step 9). After 1 hr, the solvent was removed in vacuo and the crude oil was chromatographed on silica gel using ethyl acetate/hexane (3 to 7). The product **11** (24 mg, 64%) showed a single spot on TLC ( $R_f=0.60$ ) with the same solvent system; visualization was with  $\text{MoO}\cdot\text{H}_3\text{PO}_4$ .

✓ Synthesis of 3-[<sup>18</sup>F]-fluoro-cyclobutane-1-amino-1-carboxylic acid [<sup>18</sup>F] FACBC 13:

[<sup>18</sup>F]-Fluoride was produced using the  $^{18}\text{O}(\text{p},\text{n})^{18}\text{F}$  reaction with 11 MeV protons on 95% enriched [<sup>18</sup>O] water. After evaporation of the water and drying of the fluoride by acetonitrile evaporation, the protected amino acid triflate **11** (3 mg) was introduced in an acetonitrile solution (1 mL). The no carrier added (NCA) fluorination reaction (Step 10) was performed at 85°C for 5 min in a sealed vessel in the presence of potassium carbonate and Kryptofix (Trademark Aldrich Chemical Co., Milwaukee, WI). Unreacted <sup>18</sup>F- was removed by diluting the reacting mixture with methylene chloride followed by passage through a silica gel Seppak which gave the <sup>18</sup>F labeled product **12** in 42% E.O.B. yield. Deprotection of **12** (Step 11) was achieved by using 1 mL of 4 N HCl at 115°C for

15 min and then the aqueous solution containing  $^{18}\text{F}$ ACBC **13** was passed through an ion-retardation resin (AG 11A8 50-100 mesh). The synthesis was completed in 60 min following E.O.B. with an overall radiochemical yield of 12% (17.5% E.O.B.).

5           Example 2:      Synthesis of  $[^{18}\text{F}]$ -2-Amino-3-fluoro-2-methylpropane-1-carboxylic acid **24** (FAMPC)

3-Benzylxyloxy-1,2-epoxypropane **15**

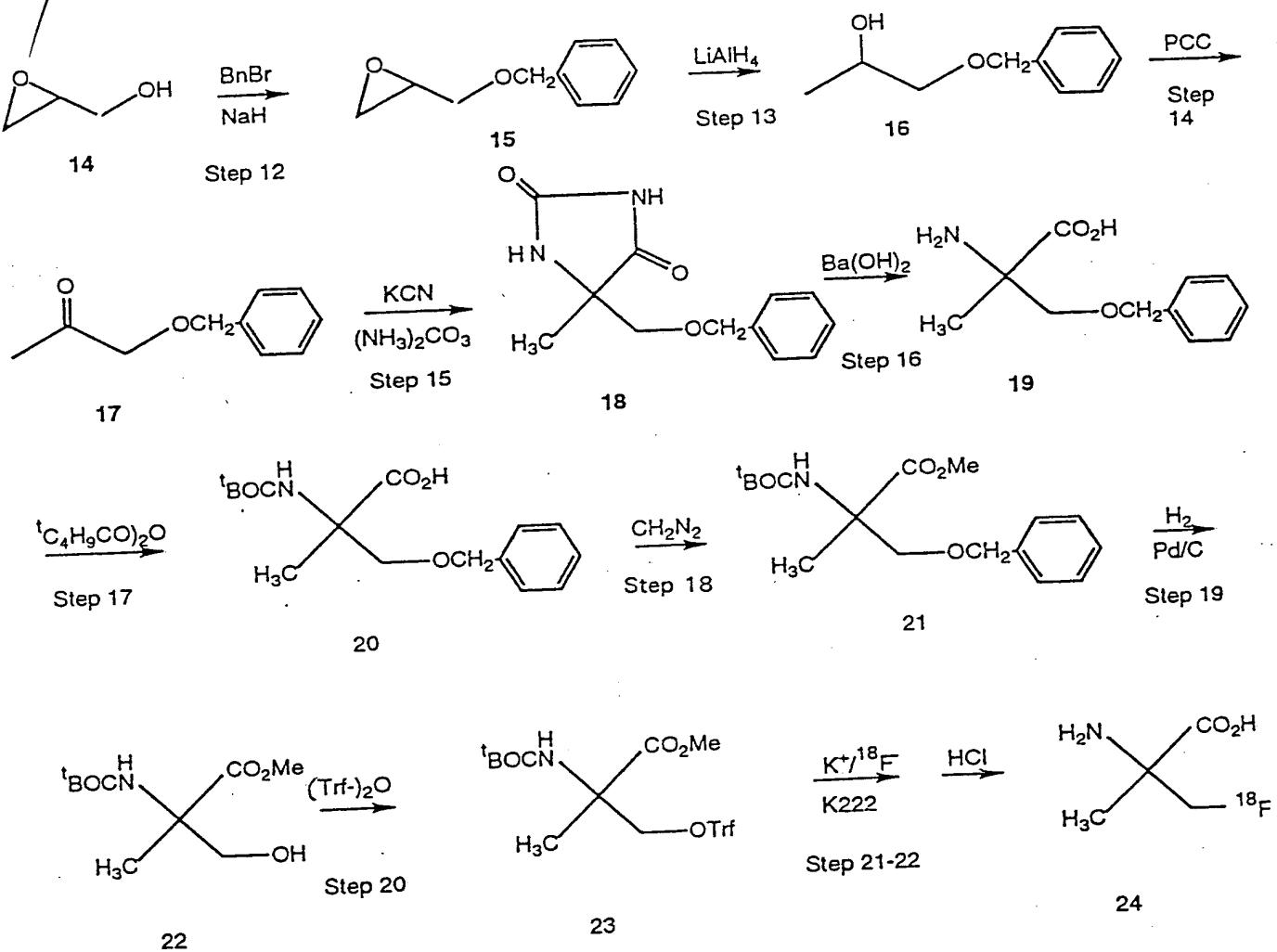
10           sodium hydride (60% oil dispersion, 23.6 g, 0.59 mol) was added in portions to a solution of glycidol (**14**) (40 g, 0.54 mol), benzyl bromide (101.5 g, 0.59 mol), and n-butyllammonium iodide (0.24 g) in dry DMF (150 mL) at 25°C (Step 12). The mixture was stirred for 1 hr at 65°C, poured over ice and then extracted with ether (2x75 mL). The combined ether extract was washed with water (3x75 mL) and dried over  $\text{MgSO}_4$ .  
15           Distillation using a 12-in vigreux column afforded 62.9 g (71%) of glycidyl benzyl ether **15**; bp 120-122°C (10 mm);  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  2.6 (dd, 1H, OCHA), 2.8 (dd, 1H, OCHb), 3.2 (m, 1H, OCHc), 3.2 (dd, 1H, OCHd), 3.8 (dd, 1H, OCHe), 4.6 (dd, 2H, OCH<sub>2</sub>), 7.23 (s, 5H, phenyl).

20           3-Benzylxylopropan-2-ol **16**

25           To a suspension of lithium aluminum hydride (6.1 g, 0.16 mol) in ether (50 mL) at 25°C was added a solution of glycidyl benzyl ether **15** (52.9 g, 0.32 mol) in 50 mL of ether (Step 13). The mixture was refluxed for 2 h and cooled to room temperature. A solution of 1 N NaOH was added dropwise to the mixture and the precipitated metal salts were removed by filtration. The ether containing the product was washed with water (50 mL), dried ( $\text{MgSO}_4$ ) and the solvent removed by roto-evaporation. Distillation gave 43.3g (82%) of 3-benzylxylopropan-2-ol; **16** bp 110-112 (5 mm).  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  1.13 (d, J=6.6 Hz, 3H, CH<sub>3</sub>), 2.5 (br s, 1H, OH), 3.28 (dd, 1H, OCH), 3.45 (dd, 1H, OCH), 4.0 (m, 1H, OCH), 4.55 (s, 2H, OCH<sub>2</sub>), 7.35 (s, 5H, phenyl).

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Synthesis of FAMPC



18

3-Benzylxypropan-2-one **17**

3-Benzylxypropan-2-ol **16** (40 g, 0.24 mol) was added to a suspension of pyridinium chlorochromate (155.2g, 0.72mol) in DMF (150 mL) at 25°C, stirred at 65°C for 3 h, and then diluted with water (75 mL) (Step 14). The mixture was extracted with ether (2x50 mL) and the combined ether layers were washed with water (3x50 mL) dried ( $\text{MgSO}_4$ ) and the solvent removed by roto-evaporation. Distillation gave 31 g (77%) of 3-benzylxypropan-2-one; **17** bp 104-106 (10 mm).  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  2.16 (s, 3H,  $\text{CH}_3$ ), 4.05 (s, 1H, OH), 4.59 (s, 2H,  $\text{OCH}_2$ ), 7.5 (s, 5H, phenyl).

2-(3-benzylxypropane)hydantoin **18**

3-Benzylxypropan-2-one **17** (25 g, 0.15 mol) was dissolved in 300 mL of 50% ethanol containing ammonium carbonate (68.3 g, 0.60 mol) and potassium cyanide (19.5 g, 0.30 mol) was added. The mixture was warmed to 60°C for 2 h and evaporated to dryness in vacuo (Step 15). The residue was extracted with 75 mL of hot methanol, filtered, and filter cake washed with 50 mL of hot methanol. The methanol solutions were combined, solvent evaporated, and the residue chromatographed on silica gel using  $\text{CH}_2\text{Cl}_2$ /methanol 90:10. Yield of 3-benzylxypropan-2-one hydantoin **18** was 23 g (66%).  $^1\text{H}$  NMR ( $d_4$ -methanol)  $\delta$  1.22 (s, 3H,  $\text{CH}_3$ ), 3.41 (d,  $J=9.6$  Hz, 1H,  $\text{OCH}_a$ ), 3.52 (d,  $J=9.6$  Hz (s, 1H,  $\text{OCH}_b$ ), 4.5 (s, 2H, NH), 4.8 (s, 2H,  $\text{OCH}_2$ ), 8.25 (m, 5H, phenyl).

2-Amino-3-benzylxy-2-methyl-1-propionic acid **19**

The hydantoin **18** (6.0 g, 25.6 mmol) was hydrolyzed by refluxing with 20 mL of a barium hydroxide solution (saturated at room temperature) for 16 hr (Step 16). The solution was neutralized to pH 6 with 2 M sulfuric acid and evaporated to dryness in vacuo. The residue was extracted with 50 mL of hot methanol, filtered, and washed with 50 mL of hot methanol. The methanol solutions were combined and evaporated. Yield of the amino acid **19** was 4.1 g (76%).

2-t-Butyl carbamate-3-benzyloxy-2-methyl-1-propionic acid **20**  
A solution of the amino acid **19** in 10 mL of a mixture of  
methanol-triethylamine (90:10) is treated with 1.0 g (4.6  
mmol) of di-*tert*-butyl dicarbonate (Step 17). The mixture is  
heated at 50-60°C for 10 min and then the solvent removed by  
roto-evaporation. The crude product is stirred in 5 mL of  
dilute HCl (pH=2) at 0°C for 10 min. The mixture is extracted  
with CH<sub>2</sub>Cl<sub>2</sub> (2x10 mL), the combined extract dried, and the  
solvent removed. The crude oil, **20**, is chromatographed on  
silica gel using methylene chloride/methanol (9 to 1) with  
0.1% formic acid.

2-(*t*-Butyl carbamate)-3-benzyloxy-2-methyl-1-methylpropionate  
**21**

To a slurry of 1-methyl-3-nitro-1-nitrosoguanidine in  
ether at 0-5°C is added a 40% solution of potassium hydroxide  
dropwise. The resultant diazomethane ether solution is added  
to 1-*t*-butyl carbamate-3-benzyloxy-1-methylpropane-1-  
carboxylic acid **20** in 3 mL of ether and the mixture is stirred  
at room temperature for 15 min (Step 18). The mixture is  
washed with water (20 mL) and the ether evaporated. The crude  
residue **21** is chromatographed on silica gel using ethyl  
acetate/hexane (1 to 9).

2-(*t*-Butyl carbamate)-3-hydroxy-2-methyl-1-propionate **22**  
A solution of the protected amino acid benzyl ether **21** in  
5 mL of methanol is mixed with a suspension of 25 mg of 10%  
palladium on charcoal in 5 mL of methanol (Step 19). The  
mixture is stirred under a positive pressure of hydrogen  
(balloon) for 16 hr. The catalyst is filtered off and the  
solvent is evaporated. The crude residue is chromatographed  
on silica gel using methylene chloride (9 to 1) to yield **22**.

2-(*t*-Butyl carbamate)-3-trifluoromethane sulfonoxy-2-methyl-1-  
methylpropionate **23**

The alcohol **22** is dissolved in 10 mL of dry methylene  
chloride and pyridine (12 μL) by stirring under N<sub>2</sub>. The  
solution is cooled to 0-5°C and 12 μL of trifluoromethane

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sulfonic anhydride is added (Step 20). After 1 hr, the solvent is removed in vacuo and the crude oil is chromatographed on silica gel using ethyl acetate/hexane (3:7) to yield 23.

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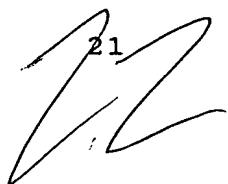
[<sup>18</sup>F]-2-Amino-3-fluoro-2-methyl-1-propionic acid 24

[<sup>18</sup>F]-Fluoride is produced using the <sup>18</sup>O(p,n)<sup>18</sup>F reaction with 11 MeV protons on 95% enriched [<sup>18</sup>O] water. After evaporation of the water and drying of the fluoride by acetonitrile evaporation, the protected amino acid triflate 23 (3 mg) is introduced in a acetonitrile solution (1 mL). The (NCA) fluorination reaction (Step 21) is performed at 85°C for 5 min in a sealed vessel in the presence of potassium carbonate and Kryptofix. Unreacted <sup>18</sup>F<sup>-</sup> is removed by diluting the reacting mixture with methylene chloride followed by passage through a silica gel Seppak which gives the <sup>18</sup>F labeled product. Deprotection (Step 22) is achieved by using 1 mL of 4 N HCl at 115°C for 15 min and then the aqueous solution is passed through an ion-retardation resin (AG 11A8 50-100 mesh) to yield 24.

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Example 3:      Synthesis of [<sup>18</sup>F]-1-Amino-3-fluoro-  
cyclopentane-1-carboxylic acid 37 (FACPC)

4-Bromo-1,2-epoxybutane 26

25        A solution of *m*-chloroperbenzoic acid (50% pure, 72.5 g, 0.21 mol) in 500 mL of methylene chloride was added dropwise to a stirred ice-cooled solution of 4-bromo-1-butene 25 (25 g, 0.19 mol) in 100 mL of methylene chloride (Step 23). After the addition, the mixture was stirred at 25°C for 18 h, during which time *m*-chlorobenzoic acid precipitated. The reaction mixture was washed with 4 N sodium hydroxide until the aqueous phase remained alkaline and with water until neutral. The organic phase was dried ( $MgSO_4$ ) and the solvent removed in vacuo to give 27.9 g (89%) of 4-bromo-1,2-epoxybutane 26. <sup>1</sup>H NMR ( $CDCl_3$ )  $\delta$  2.10 (m, 2H, O-C-CH<sub>2</sub>), 2.58 (d, d J=5.0, 2.6Hz, 1H, OCHa) 2.82 (dd J=5.0, 4.0Hz), 1H, OCHb), 3.09 (m, 2H, O-C-CH<sub>2</sub>, 3.55 (t, J=7Hz, 2H).

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Diethyl 3-hydroxycyclopentane-1,1-dicarbonate **27**

A solution of diethyl malonate (7.7 g, 48.5 mmol) in 53.4 mL of 1 N ethanolic sodium ethoxide was stirred for 15 min in a ice bath, after which 4-bromo-1,2-epoxybutane **26** (14.6 g, 97 mmol) was added (Step 24). After stirring at 25°C for 3 h, the mixture was poured into water and the ethanol evaporated *in vacuo*. The aqueous solution was extracted with chloroform, the extracts dried ( $\text{MgSO}_4$ ) and concentrated. Distillation gave 8.14 g (73%) of product **27**; bp 155–160°C (0.5 mm);  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  1.3 (t,  $J=7.2\text{Hz}$ , 6H,  $\text{CH}_3$ ), 1.7–2.7 (m, 6H,  $\text{CH}_2$ ), 3.02 (s, 1H, OH), 4.2 (q,  $J=7.2\text{Hz}$ , 4H,  $\text{O}=\text{COCH}_2$ ), 4.2 (m, 1H, OCH).

Diethyl 3-benzyloxycyclopentane-1,1-dicarboxylate **28**

Sodium hydride (60% oil dispersion, 2.1 g, 53 mmol) was added in portions to a solution of diethyl 3-hydroxycyclopentane-1,1-dicarboxylate **27** (11 g, 48 mmol), benzyl bromide (9.7 g, 53 mol), and *n*-tetrabutylammonium iodide (100 mg) in dry DMF (50 mL) at 25°C (Step 25). The mixture was stirred for 1 hr at 65°C, poured onto ice and then extracted with ether (2x50 mL). The combined either extract was washed with water (3x50 mL) and dried over  $\text{MgSO}_4$ . Chromatography on silica gel (10:90 ethyl acetate/hexane,  $R_f=0.38$ ) afforded 11.6 g (75%) of the benzyl ether **28**;  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  1.3 (t,  $J=7.2\text{Hz}$ , 6H,  $\text{CH}_3$ ), 1.7–2.7 (m, 6H,  $\text{CH}_2$ ), 4.2 (q,  $J=7.2\text{Hz}$ , 4H,  $\text{O}=\text{COCH}_2$ ), 4.1 (m, 1H, O-CH), 4.6 (s, 2H, O- $\text{CH}_2$ ), 7.3 (s, 5H, phenyl).

3-Benzylloxycyclopentane-1,1-dicarboxamine **29**

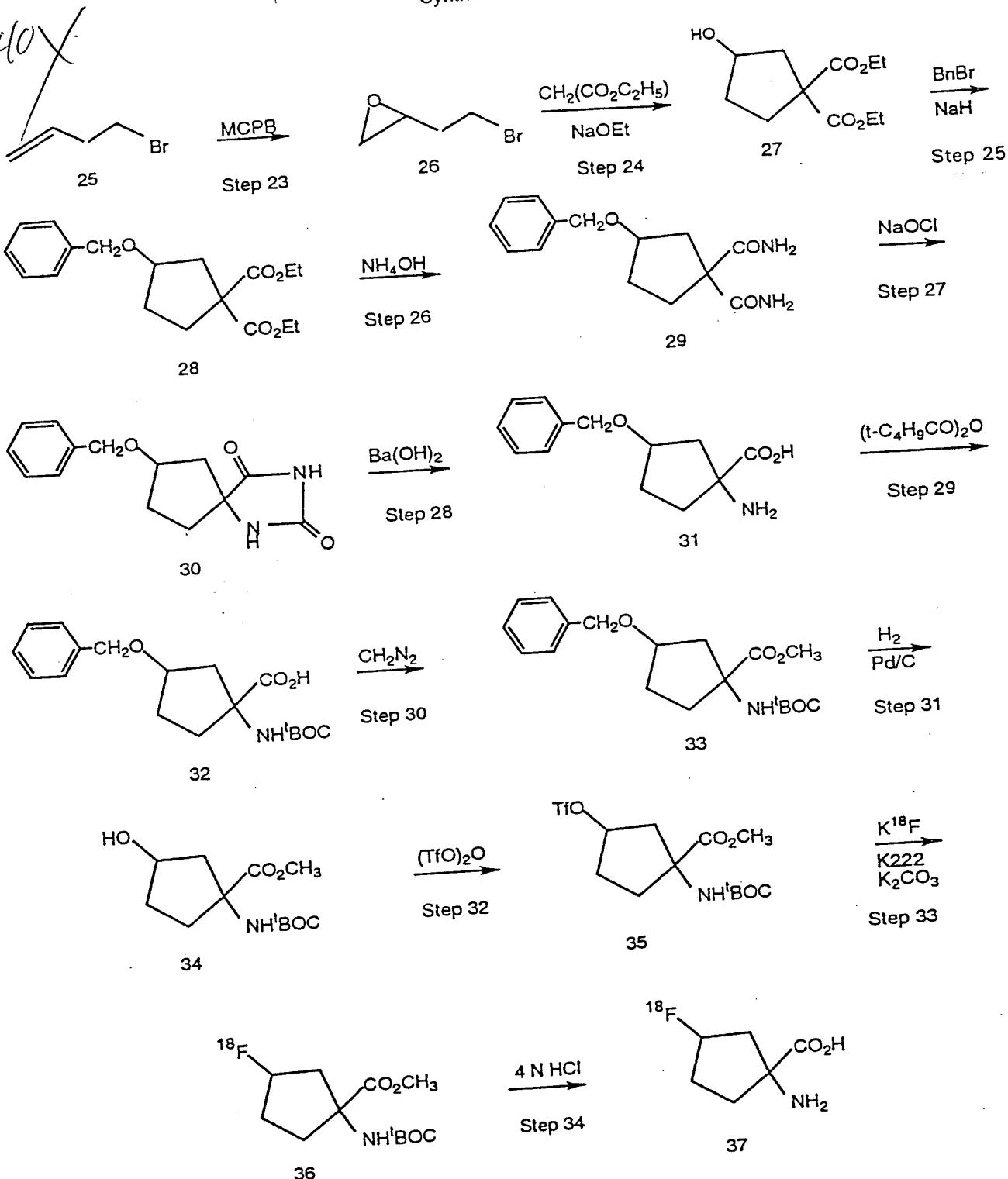
Diethyl 3-benzyloxycyclopentane-1,1-dicarboxylate **28** (10 g, 31 mmol) is stirred with concentrated aqueous ammonia (100 mL) for four days at room temperature (Step 26). The resultant diamide **29** is collected by filtration and washed with water followed by ethyl acetate.

Cis/trans 5-(3-benzyloxycyclopentane)hydantoin **30**

3-Benzylloxycyclopentane-1,1-dicarboxamine **29** is stirred in 150 mL of dilute sodium hypochlorite (Aldrich product/water

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Synthesis of FACPC



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1:2) at 0-5°C for 4 hr and then allowed to stand overnight at room temperature (Step 26). Unreacted diamide will be recovered by filtration. The solution is neutralized to pH 5 with concentrated hydrochloric acid and evaporated to dryness in vacuo. The residue is extracted with 50 mL of hot methanol, filtered, and washed with 50 mL of hot methanol. The methanol solutions are combined and evaporated.

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1-Amino-3-benzyloxycyclopentanecarboxylate acid 31

The hydantoin 30 is hydrolyzed by refluxing with 10 mL of a barium hydroxide solution (saturated at room temperature) for 16 hr (Step 28). The solution is neutralized to pH 6 with 2 M sulfuric acid and evaporated to dryness in vacuo. The residue is extracted with 50 mL of hot methanol, filtered, and washed with 50 mL of hot methanol. The methanol solutions are combined and evaporated.

1-t-Butyl carbamate-3-benzyloxy-1-cyclopentane-1-carboxylic acid

32

20 A solution of the amino acid 31 in 10 mL of a mixture of methanol/triethylamine (90:10) is treated with di-tert-butyl dicarbonate (Step 29). The mixture is heated at 50-60°C for 10 min and then the solvent is removed by rotovaporation. The crude product is stirred in 5 mL of dilute HCl (pH=2) at 0°C for 10 min. The mixture is extracted with CH<sub>2</sub>Cl<sub>2</sub> (2x10 mL), the combined extract dried, and the solvent removed. The crude oil is chromatographed on silica gel using methylene chloride/methanol (9 to 1) with 0.1% formic acid to yield 32.

30 1-t-Butyl carbamate-3-benzyloxy-1-cyclopentane-1-carboxylic acid methyl ester 33

To a slurry of 1-methyl-3-nitro-1-nitrosoguanidine in ether at 0-5°C will be added to a 40% solution of potassium hydroxide dropwise. The resultant diazomethane ether solution is added to 35 1-t-butyl carbamate-3-benzyloxycyclopentane-1-carboxylic acid 32 in 3 mL of ether and the mixture is stirred at room temperature for 15 min (Step 30). The mixture is washed with water (10 mL)

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and the ether evaporated. The crude residue is chromatographed on silica gel using ethyl acetate/hexane (1 to 9) to yield 33.

1-t-Butyl carbamate-3-hydroxy-1-cyclopentane-1-carboxylic acid  
5 méthyl ester 34

A solution of the protected amino acid benzyl ether 33 in 5 mL of methanol is mixed with a suspension of 25 mg of 10% palladium on charcoal in 5 mL of methanol (Step 31). The mixture is stirred under a positive pressure of hydrogen (balloon) for 16 hr. The catalyst is filtered off and the solvent is evaporated. The crude residue is chromatographed on silica gel using methylene chloride/methanol (9 to 1) to yield 34.

15 1-t-Butyl carbamate-3-trifluoromethane sulfonoxy-1-cyclopentane-1-carboxylic acid methyl ester 35

The alcohol is dissolved in 10 mL of dry methylene chloride and pyridine (12  $\mu$ L) by stirring under  $N_2$ . The solution is cooled to 0-5°C and 12  $\mu$ L of trifluoromethane sulfonic anhydride is added (Step 32). After 1 hr, the solvent is removed in vacuo and the crude oil is chromatographed on silica gel using ethyl acetate/hexane (3:7) to yield 35.

20  $[^{18}F]$ -1-Amino-3-fluorocyclopentane-1-carboxylic acid 37

$[^{18}F]$ -Fluoride will be produced using the  $^{18}O(p,n)^{18}F$  reaction with 11 MeV protons on 95% enriched  $[^{18}O]$  water. After evaporation of the water and drying of the fluoride by acetonitrile evaporation, the protected amino acid triflate 35 (3 mg) is introduced in an acetonitrile solution (1 mL). The (NCA) fluorination reaction is performed at 85°C for 5 min in a sealed vessel in the presence of potassium carbonate and Kryptofix (Step 33). Unreacted  $^{18}F^-$  is removed by diluting the reacting mixture with methylene chloride followed by passage through a silica gel Seppak which gives the  $^{18}F$  labeled product 36. Deprotection (Step 34) is achieved by using 1 mL of 4 N HCl at 115°C for 15 min and then the aqueous solution is passed through an ion-retardation resin (AG 11A8 50-100 mesh) to yield 37 (FACPC).

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Example 4:

[<sup>18</sup>F]-1-Amino-4-fluoro-cyclohexane-1-carboxylic acid  
49 (FACHCl)

4-Hydroxycyclohexanone ethylene ketal **49**

Sodium borohydride (2.4 g, 64 mmol) was added in portions to a stirred ice cold solution of 1,4 cyclohexanedione monoethylene ketal **38** (20 g, 128 mmol) in 60 mL of methanol (Step 35). After addition was complete, 1 N HCl was added to the solution dropwise until a pH of 8 was obtained and then the solvent was removed by roto-evaporation. The product **39** (16.8 g, 84%) showed a single spot on TLC ( $R_f=0.4$ , ethyl acetate/hexane 20:80 solvent system, visualization was with acidic vanillin ethanol solution) and was used without further purification.  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  1.6-1.9 (m, 8H, ring- $\text{CH}_2$ ), 3.8 (m, 1H,  $\text{CH}-\text{O}$ ), 4.0 (s, 4H, ketal- $\text{CH}_2$ ), 5.3 (s, 1H, OH).

4-Benzylloxycyclohexanone ethylene ketal **40**

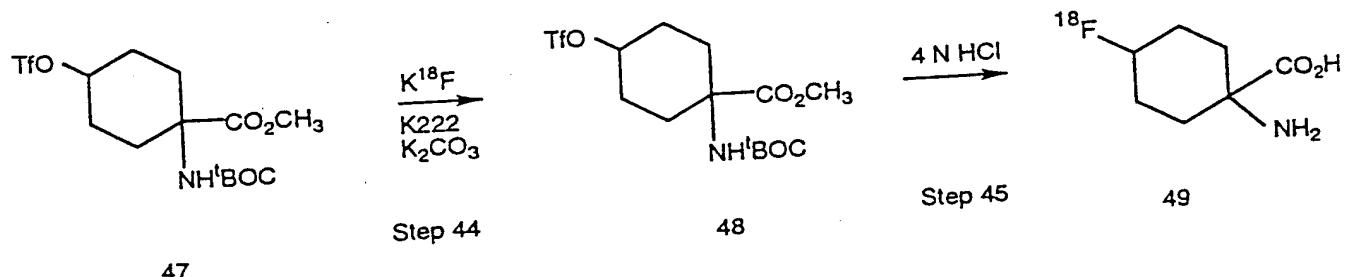
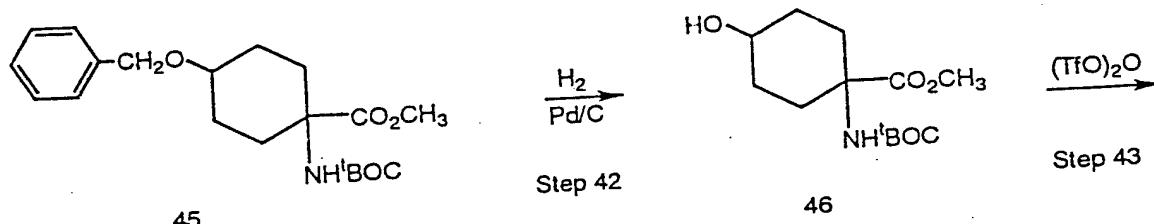
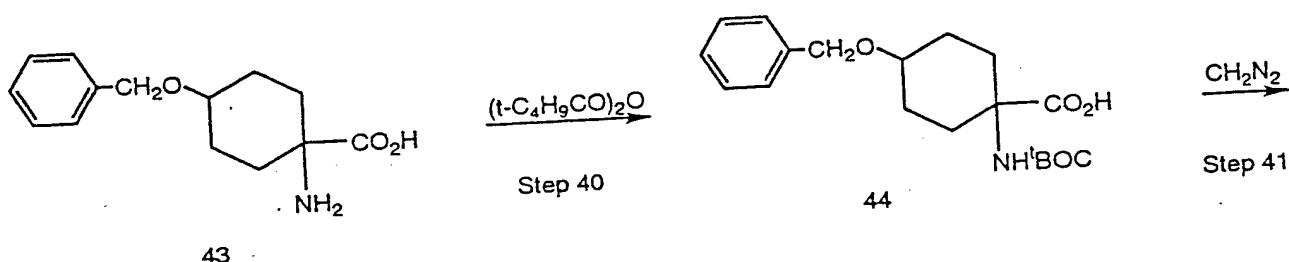
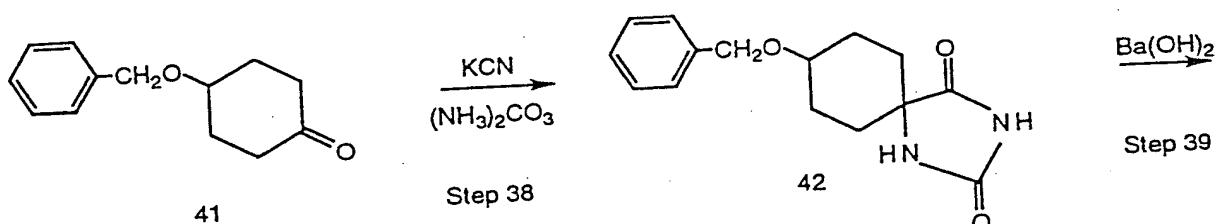
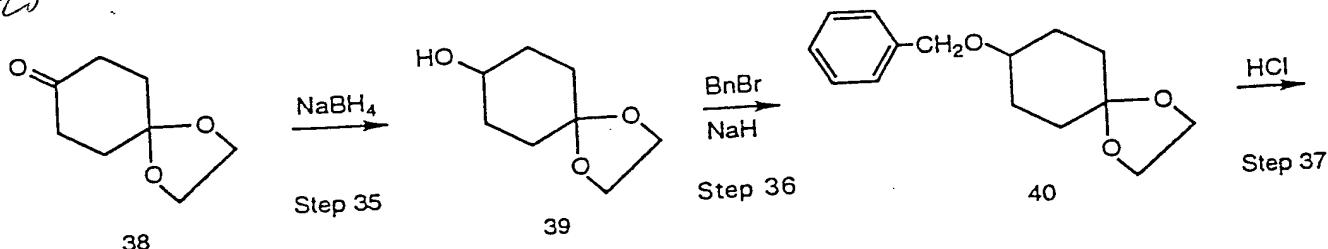
Sodium hydride (60% oil dispersion, 2.2 g, 56 mmol) was added in portions to a solution of 6-hydroxycyclohexanone ethylene ketal **39** (8.8 g, 51 mmol), benzyl bromide (9.6 g, 5.6 mmol), and tetra-*n*-butylammonium iodide (50 mg) in dry DMF (50 mL) at 25°C (Step 36). The mixture was stirred for 1 hr at 65°C, poured over ice and then extracted with ether (2x50 mL). The combined ether extract was washed with water (3x50 mL), dried ( $\text{MgSO}_4$ ) and solvent was removed. Chromatography on silica gel using 10:90 ethyl acetate/hexane ( $R_f=0.39$ ) afforded 8.9g (70%) of the benzyl ether **40**.  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  1.6-1.9 (m, 8H, ring- $\text{CH}_2$ ), 3.6 (m, 1H,  $\text{CH}-\text{O}$ ), 4.0 (s, 2H, ketal- $\text{CH}_2$ ), 4.6 (s, 2H,  $\text{CH}_2-\text{O}$ ).

4-Benzylloxycyclohexanone **41**

A solution of 4-benzylxy cyclohexanone ethylene ketal **40** (5.0 g, 20.1 mmol) in methanol (20 mL) and 1N HCl (0.5 mL) was stirred overnight at 25°C (Step 37). The mixture was neutralized by addition of 1 N  $\text{NaHCO}_3$  (0.5 mL), solvent removed by roto-evaporation, and the residue chromatographed on silica gel using 15:85 ethyl acetate /hexane. Yield of the ketone **41** was 2.7 g

Synthesis of FACHC

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(67%);  $R_f$ =0.35;  $^1H$  NMR ( $CDCl_3$ )  $\delta$  2.3 (m, 8H, ring- $CH_2$ ), 3.6 (m, 1H,  $CH_2-O$ ), 4.6 (s, 2H,  $CH_2-O$ ).

4-Benzylloxycyclohexanone hydantoin 42

4-Benzylloxycyclohexanone 41 is dissolved in 30 mL of 50% ethanol containing ammonium carbonate and potassium cyanide is added (Step 38). The mixture will be warmed to 60°C for 2 h and evaporated to dryness *in vacuo*. The residue is extracted with 40 mL of hot methanol, filtered, and the filter cake washed with 20 mL of hot methanol. The methanol solutions are combined, solvent evaporated, and the residue chromatographed on silica gel using  $CH_2Cl_2$ /methanol 90:10 to yield 42.

1-Amino-4-benzylloxycyclohexane-1-carboxylic acid 43

The hydantoin 42 is hydrolyzed by refluxing with 10 mL of a barium hydroxide solution (saturated at room temperature) for 16 h (Step 39). The solution is neutralized to pH 6 with 2 N sulfuric acid and evaporated to dryness *in vacuo*. The residue is extracted with 50 mL of hot methanol, filtered, and washed with 50 mL of hot methanol. The methanol solutions are combined and evaporated.

1-t-Butyl carbamate-3-benzylxy-1-cyclohexane-1-carboxylic acid 44

A solution of the amino acid in 10 mL of a mixture of methanol/triethylamine (90:10) is treated with di-tert-butyl dicarbonate (Step 40). The mixture is heated at 50-60°C for 10 min and then the solvent is removed by rotovaporation. The crude product is stirred in 5 mL of dilute HCl (pH=2) at 0°C for 10 min. The mixture is extracted with  $CH_2Cl_2$  (2x10 mL), the combined extract dried, and the solvent removed. The crude oil is chromatographed on silica gel using methylene chloride/methanol (9 to 1) with 0.1% formic acid to yield 44.

1-t-Butyl carbamate-3-benzylxy-1-cyclohexane-1-carboxylic acid methyl ester 45

To a slurry of 1-methyl-3-nitro-1-nitrosoguanidine in ether at 0-5°C is added to a 40% solution of potassium hydroxide dropwise. The resultant diazomethane ether solution is added to 1-t-Butyl

carbamate-3-benzyloxy-1-cyclohexane-1-carboxylic acid 44 in 3 mL of ether and the mixture is stirred at room temperature for 15 min (Step 41). The mixture is washed with water (10 mL) and the ether evaporated. The crude residue is chromatographed on silica gel using ethyl acetate/hexane (1 to 9) to yield 45.

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1-t-Butyl carbamate-3-hydroxy-1-cyclobutane-1-carboxylic acid methyl ester 46

A solution of the protected amino acid benzyl ether 45 in 5 mL of methanol is mixed with a suspension of 25 mg of 10% palladium on charcoal in 5 mL of methanol (Step 42). The mixture is stirred under a positive pressure of hydrogen (balloon) for 16 hr. The catalyst is filtered off and the solvent is evaporated. The crude residue is chromatographed on silica gel using methylene chloride/methanol (9 to 1) to yield 46.

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1-t-Butyl carbamate-3-trifluoromethane sulfonoxy-1-cyclohexane-1-carboxylic acid methyl ester 47

The alcohol 46 is dissolved in 10 mL of dry methylene chloride and pyridine (12  $\mu$ L) by stirring under  $N_2$ . The solution is cooled to 0-5°C and 12  $\mu$ L of trifluoromethane sulfonic anhydride is added (Step 43). After 1 hr, the solvent is removed in vacuo and the crude oil is chromatographed on silica gel using ethyl acetate/hexane (3:7).

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[ $^{18}F$ ]-1-Amino-3-fluorocyclohexane-1-carboxylic acid 49

[ $^{18}F$ ]-Fluoride is produced using the  $^{18}O(p,n)^{18}F$  reaction with 11 MeV protons on 95% enriched [ $^{18}O$ ] water. After evaporation of the water and drying of the fluoride by acetonitrile evaporation, the protected amino acid triflate 47 (3 mg) is introduced in an acetonitrile solution (1 mL). The (NCA) fluorination reaction is performed at 85°C for 5 min in a sealed vessel in the presence of potassium carbonate and Kryptofix (Step 44). Unreacted  $^{18}F^-$  is removed by diluting the reacting mixture with methylene chloride followed by passage through a silica gel Seppak which gives the  $^{18}F$  labeled product. Deprotection (Step 45) is achieved by using 1 mL of 4 N HCl at 115°C for 15 min and then the aqueous solution is

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passed through an ion-retardation resin (AG 11A8 50-100 mesh) to yield FACHC 49.

Example 5:  $[^{18}\text{F}]\text{-1-Amino-3-(fluoromethyl)cyclobutane-1-carboxylic acid}$  60

Dimethyl ester 3-hydroxycyclobutane-1,1-dicarboxylate 51

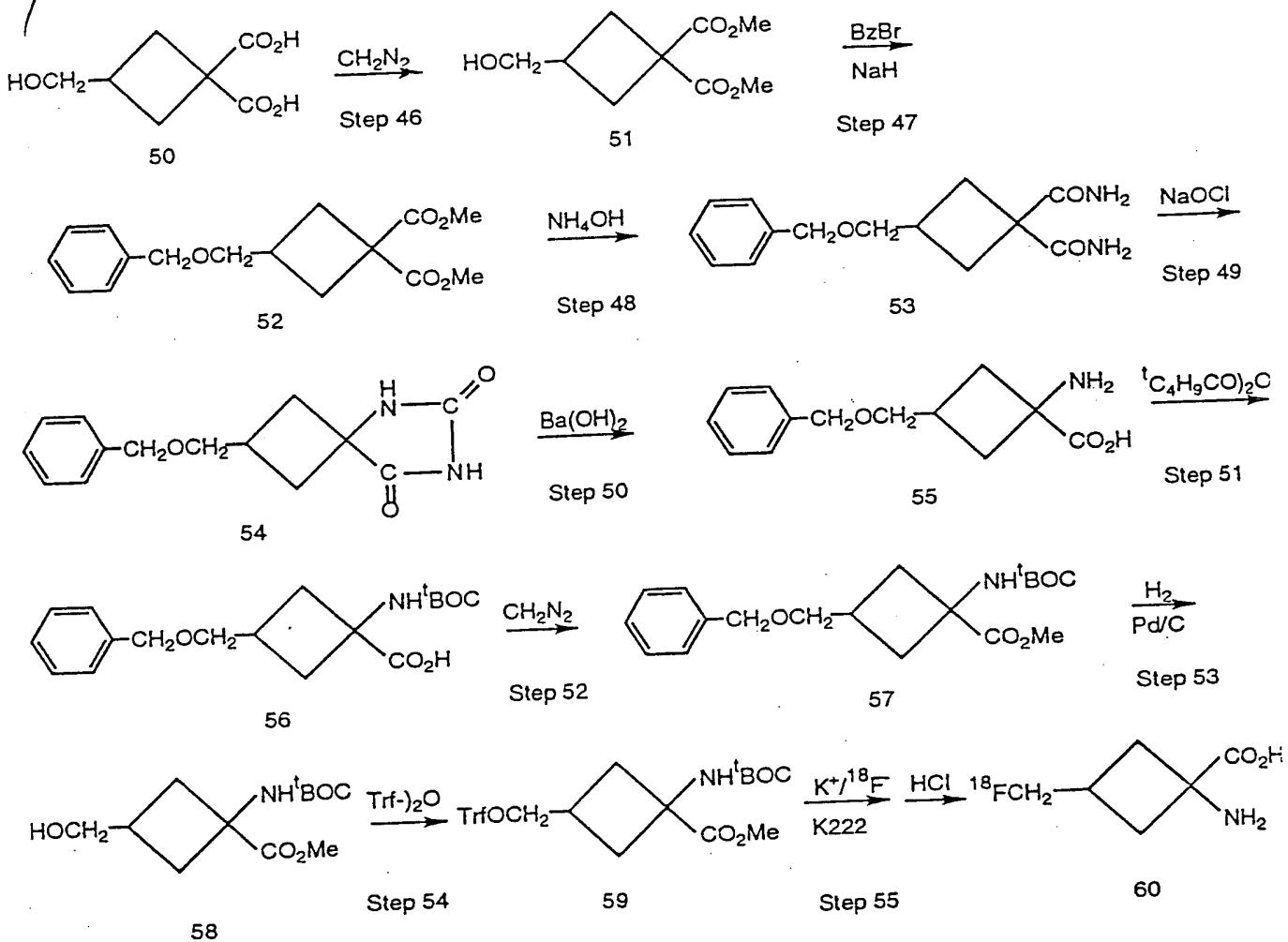
To a slurry of 1-methyl-3-nitro-1-nitrosoguanidine (150 mg) in 8 mL of ether at 0-5°C was added a 40% solution of potassium hydroxide dropwise. The resultant diazomethane ether solution was added to 0.15 g (0.50 mmol) of 50 in 3 mL of ether and the mixture was stirred at room temperature for 15 min (Step 46). The mixture was washed with water (10 mL) and the ether evaporated. The crude residue was chromatographed on Silica gel.

Dimethyl 3-(benzyloxymethyl)cyclobutane-1,1-dicarboxylate 52

Sodium hydride (60% oil dispersion, 2.1 g, 53 mmol) is added in portions to a solution of dimethyl 3-(hydroxymethyl)cyclobutane-1,1-dicarboxylate (51), benzyl bromide, and *n*-tetrabutylammonium iodide in dry DMF at 25°C (Step 47). The mixture is stirred for 1 hr at 65°C, poured onto ice and then extracted with ether (2 x 50 mL). The combined ether extract is washed with water (3 x 50 mL) and dried over  $\text{MgSO}_4$ . Chromatography on silica gel.

[<sup>18</sup>F]-1-Amino-3-(fluoromethyl)cyclobutane-1-carboxylic acid

T0320X



3-(Benzylloxymethyl)cyclobutane-1,1-dicarboxamine 53

Dimethyl 3-(benzylloxymethyl)cyclobutane-1,1-dicarboxylate (52) is stirred with concentrated aqueous ammonia (100 mL) for four days at room temperature (Step 48). The resultant diamide is collected by filtration and washed with water followed by ethyl acetate.

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Cis/trans 5-((3-benzylloxymethyl)cyclobutane)hydantoin 54

3-(Benzylloxymethyl)cyclopentane-1,1-dicarboxamine (53) is stirred with dilute sodium hypochlorite (Aldrich product/water 1:2) at 0-5°C for 4 hr and then allowed to stand overnight at room temperature (Step 49). Unreacted diamide is recovered by filtration. The solution is neutralized to pH 5 with concentrated hydrochloric acid and evaporated to dryness in vacuo. The residue is extracted with 50 mL of hot methanol, filtered, and washed with 50 mL of hot methanol. The methanol solutions are combined and evaporated.

1-Amino-3-(benzylloxymethyl)cyclobutane-1-carboxylic acid 55

The hydantoin 54 is hydrolyzed by refluxing with 10 mL of a barium hydroxide solution (saturated at room temperature) for 16 hr (Step 50). The solution is neutralized to pH 6 with 2 M sulfuric acid and evaporated to dryness in vacuo. The residue is extracted with 50 mL of hot methanol, filtered, and washed with 50 mL of hot methanol. The methanol solutions are combined and evaporated.

1-t-Butyl carbamate-3-(benzylloxymethyl)cyclobutane-1-carboxylic acid 56

A solution of the amino acid (55) in 10 mL of a mixture of methanol/triethylamine (90:10) is treated with di-tert-butyl dicarbonate (Step 51). The mixture is heated at 50-60°C for 10 min and then the solvent is removed by rotovaporation. The crude product is stirred in 5 mL of dilute HCl (pH=2) at 0°C for 10 min. The mixture is extracted with  $\text{CH}_2\text{Cl}_2$  (2x10 mL), the combined extract dried, and the solvent removed. The crude oil is

chromatographed on silica gel using methylene chloride/methanol (9 to 1) with 0.1% formic acid.

5           1-t-Butyl carbamate-3-(benzyloxymethyl)cyclobutane-1-carboxylic acid methyl ester 57

To a slurry of 1-methyl-3-nitro-1-nitrosoguanidine in ether at 0-5°C is added a 40% solution of potassium hydroxide dropwise. The resultant diazomethane ether solution is added to carboxylic acid 56 in ether and the mixture is stirred at room temperature for 15 min. (Step 52). The mixture is washed with water and the ether evaporated. The crude residue is chromatographed on silica gel using ethyl acetate/hexane (1 to 9).

15           1-t-Butyl carbamate-3-(hydroxymethyl)cyclobutane-1-carboxylic acid methyl ester 58

A solution of the protected amino acid benzyl ether 57 in methanol is mixed with a suspension of 10% palladium on charcoal in 5 mL of methanol (Step 53). The mixture is stirred under a positive pressure of hydrogen (balloon) for 16 hr. The catalyst is filtered off and the solvent is evaporated. The crude residue is chromatographed on silica gel using methylene chloride/methanol (9 to 1).

25           1-t-Butyl carbamate-3-(trifluoromethane sulfonyloxymethyl)cyclobutane-1-carboxylic acid methyl ester 59

The alcohol 58 is dissolved in 10 mL of dry methylene chloride and pyridine (12 μL) by stirring under N<sub>2</sub>. The solution is cooled to 0-5°C and 12 μL of trifluoromethane sulfonic anhydride is added (Step 54). After 1 hr, the solvent is removed in vacuo and the crude oil is chromatographed on silica gel using ethyl acetate/hexane (3:7).

30           [<sup>18</sup>F]-1-Amino-3-(fluoromethyl)cyclobutane-1-carboxylic acid 60  
35           [<sup>18</sup>F]-Fluoride is produced using the <sup>18</sup>O(p,n)<sup>18</sup>F reaction with 11 MeV protons on 95% enriched [<sup>18</sup>O] water. After evaporation of the water and drying of the fluoride by acetonitrile evaporation, the protected amino acid triflate 58 (3 mg) is introduced in an

acetonitrile solution (1 mL). The (NCA) fluorination reaction is performed at 85°C for 5 min in a sealed vessel in the presence of potassium carbonate and Kryptofix (Step 55). Unreacted <sup>18</sup>F<sup>-</sup> is removed by diluting the reacting mixture with methylene chloride followed by passage through a silica gel Seppak which gives the <sup>18</sup>F labeled product. Deprotection of 59 is achieved by using 1 mL of 4 N HCl at 115°C for 15 min (Step 56) and then the aqueous solution is passed through an ion-retardation resin (AG 11A8 50-100 mesh).

Example 6: Synthesis of [<sup>123</sup>I]-1-Amino-3-iodocyclobutane-1-carboxylic acid 61

[<sup>123</sup>I]-Sodium iodide (10 mCi, 0.1 N NaOH solution) is dried by acetonitrile (2 mL) evaporation, the protected amino acid triflate 11 (3 mg) is introduced in an acetonitrile solution (1 mL) (Step 57). The (NCA) iodination reaction is performed at 85°C for 5 min in a sealed vessel. Unreacted <sup>18</sup>F<sup>-</sup> is removed by diluting the reacting mixture with methylene chloride followed by passage through a silica gel Seppak which gives the <sup>18</sup>I labeled product. Deprotection is achieved by using 1 mL of 4 N HCl at 115°C for 15 min (Step 58) and then the aqueous solution is passed through an ion-retardation resin (AG 11A8 50-100 mesh).

Example 7: Synthesis of [<sup>123</sup>I]-1-Amino-3-iodocyclobut-2-ene-1-carboxylic acid 65

1-t-Butyl carbamate-3-oxo-1-cyclobutane-1-carboxylic acid methyl ester 62

The protected alcohol 10 is added to a suspension of pyridinium chlorochromate in DMF at 25°C, stirred at 65°C for 3 h, and then diluted with water (75 mL) (Step 59). The mixture is extracted with ether (2x50 mL) and the combined ether layers were washed with water, dried (MgSO<sub>4</sub>) and the solvent removed by rotovaporation.

[1-t-Butyl carbamate-1-cyclobutane-1-carboxylic acid methyl ester]  
3-hydrazone **63**

A mixture of hydrazine, ketone **62**, DBN, and 20 mL of ethanol  
is heated to boiling (Step 60). The mixture is kept hot for 10  
min. The solution is cooled, and the hydrazone is collected by  
filtration.

[<sup>123</sup>I]-1-Amino-3-iodo-cyclobut-2-ene-1-carboxylic acid **65**

Aqueous 3% hydrogen peroxide is added to a mixture of sodium  
[<sup>123</sup>I]iodide, hydrazone **63**, and 0.1 N HCl in a sealed vial  
protected by a charcoal vent (Step 61). The reaction is allowed  
to proceed for 30 min at ambient temperature, quenched with a  
solution of sodium bisulfite (300 mg/mL). Deprotection of **64**  
(Step 62) is achieved by using 1 mL of 4 N HCl at 115°C for 15 min  
and then the aqueous solution is passed through an ion-retardation  
resin (AG 11A8 50-100 mesh).

Example 8:      Synthesis of E-[<sup>123</sup>I]-1-Amino-3-(2-  
                      iodoethyl)cyclobutane-1-carboxylic acid **69**

1-t-Butyl carbamate-3-bromo-1-cyclobutane-1-carboxylic acid methyl  
ester **66**

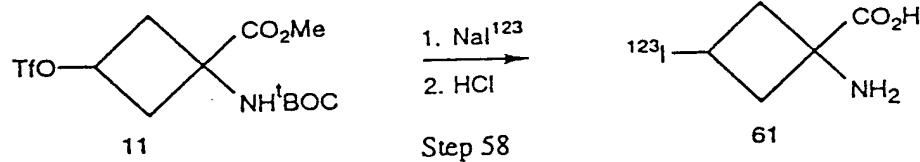
Bromine is added to a mixture of alcohol **10** and  
triphenylphosphine in DMF at -10°C (Step 63). After stirring for  
1 h, the mixture is diluted with water and extracted with ether.  
The ether layer is washed with water, 10% sodium sulfite, and then  
dried. The ether is removed and the residue is chromatographed on  
silica gel.

1-t-Butyl carbamate-3-ethynyl-1-cyclobutane-1-carboxylic acid  
methyl ester **67**

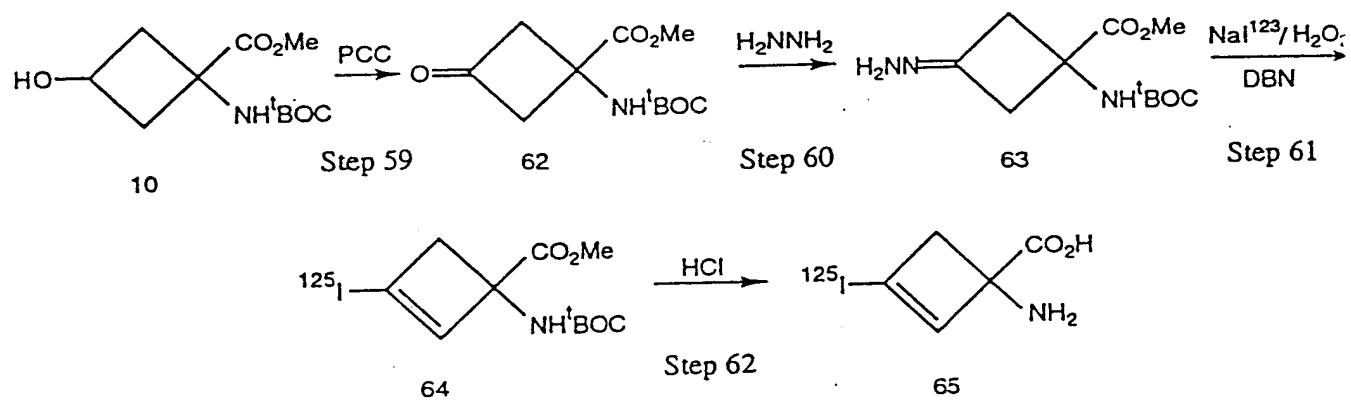
The bromo compound **66** in THF is added to a suspension of  
lithium acetylidyne ethylenediamine complex in THF stirred at 0°C  
under a nitrogen atmosphere (Step 64). The mixture is stirred for  
3 h at 25°C, poured into ice water, and extracted with ether. The  
ether extract is washed with ice cold 1 N HCl, brine and then  
dried. The ether is removed and the residue is chromatographed on  
silica gel.

### [123I]-1-Amino-3-iodocyclobutane-1-carboxylic acid

10370X



#### [123I]-1-Amino-3-iodocyclobut-2-ene-1-carboxylic acid



36

36

1-t-Butyl carbamate-3-((E)-2-tributylstannylethenyl)-1-cyclobutane-1-carboxylic acid methyl ester **68**

Tributyltin hydride, the alkyne **67** and azobisisobutyronitrile are refluxed in toluene under nitrogen atmosphere for 10 h (Step 5 65). The reaction mixture is cooled, solvent removed *in vacuo*, and the residue chromatographed on silica gel.

[<sup>123</sup>I]-1-Amino-3-((E)-2-iodoethenyl)cyclobut-2-ene-1-carboxylic acid **69**

Aqueous 3% hydrogen peroxide is added to a mixture of sodium [<sup>125</sup>I]iodide, tributylstannyl **68**, and 0.1 N HCl in a sealed vial protected by a charcoal vent (Step 66). The reaction is allowed to proceed for 30 min at ambient temperature, quenched with a solution of sodium bisulfite (300 mg/mL). Deprotection (Step 67) is achieved by using 1 mL of 4 N HCl at 115°C for 15 min and then the aqueous solution is passed through an ion-retardation resin (AG 11A8 50-100 mesh).

Example 9:      Synthesis of [<sup>123</sup>I]-1-Amino-3-(iodomethylene)cyclobutane-1-carboxylic acid

(Bromomethyl)triphenylphosphonium bromide **70**

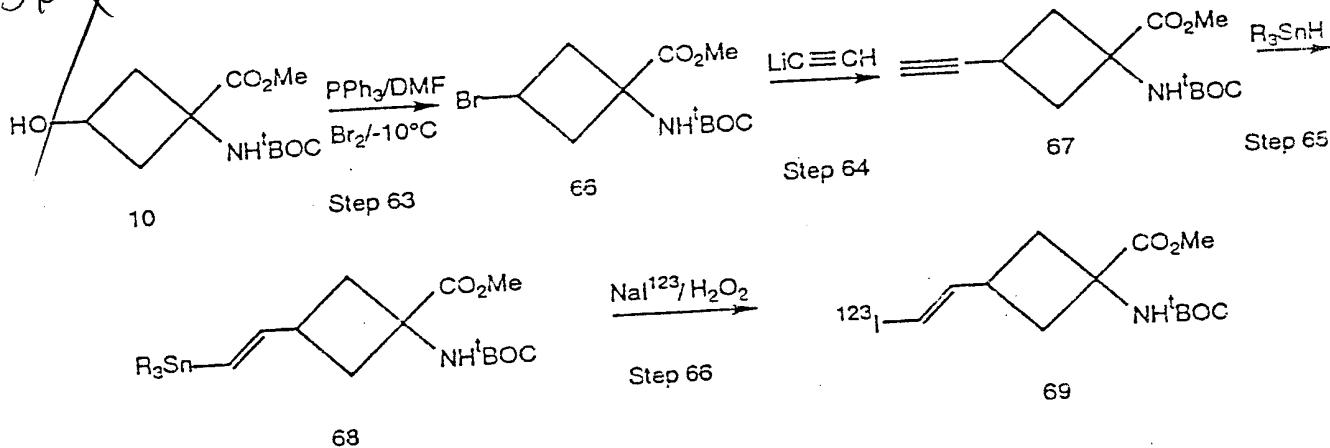
A mixture of hydroxymethyl)triphenylphosphonium bromide and phosphorus tribromide in benzene is heated at reflux for 23 h with stirring. After this time the solution is dark orange and an orange solid is present. The mixture is cooled to 25°C and methanol is added. The solvent was removed at reduced pressure and the residue treated with water to extract the phosphonium salt. The aqueous extracts were saturated with solid potassium bromide and extracted with chloroform. The phosphonium salts are crystallized from hot chloroform by addition of ethyl acetate.

1-t-Butyl carbamate-3-(bromomethylene)-1-cyclobutane-1-carboxylic acid methyl ester **71**

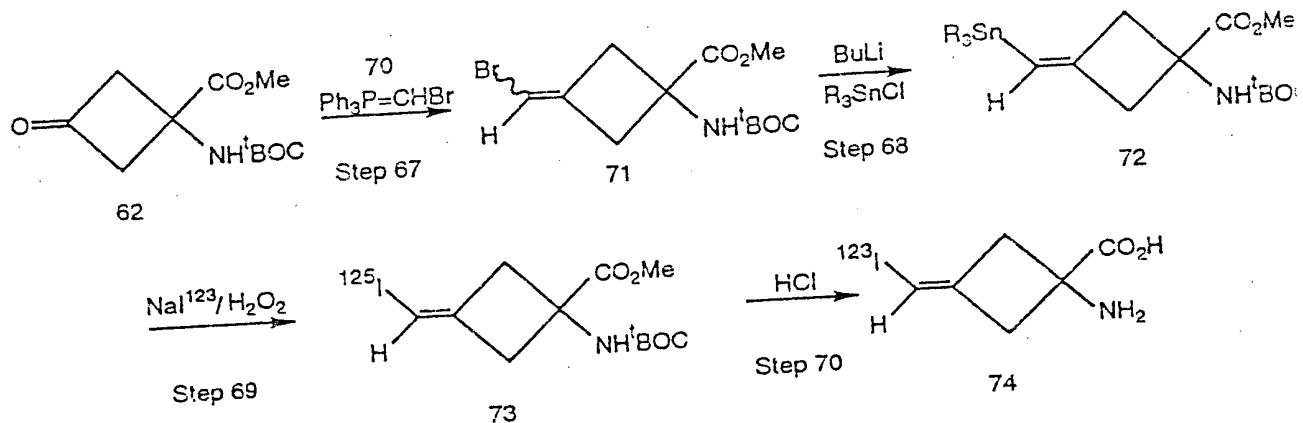
The phosphonium salt **70** is suspended in ether and ethereal phenyllithium is added rapidly at 25°C. An orange-yellow solution results which becomes mustard yellow within 2 h. To this solution is added protected ketone **62** and the reaction mixture is heated at

[123]-1-Amino-3-(2-iodoethenyl)cyclobutane-1-carboxylic acid

10390X



[123I]-1-Amino-3-(iodomethylene)cyclobutane-1-carboxylic acid



38

reflux for 8 h with stirring (Step 68). The ether is removed and the residue is chromatographed on silica gel.

5           **1-t-Butyl carbamate-3-(tributylstannylmethylenyl)-1-cyclobutane-1-carboxylic acid methyl ester 72**

To a solution of 71 in ether at -78°C is added *t*-butyllithium (2 eq.) after 15 min tributyltin chloride is added and the mixture is warmed to 25°C (Step 69). The reaction mixture is poured into ice water and the ether layer separated and dried. The ether is 10 removed and the residue is chromatographed on silica gel.

[<sup>123</sup>I]-1-Amino-3-(iodomethylenyl)cyclobutane-1-carboxylic acid 74

Aqueous 3% hydrogen peroxide is added to a mixture of sodium [<sup>125</sup>I]iodide, tributylstannyl 72, and 0.1 N HCl in a sealed vial 15 protected by a charcoal vent (Step 70). The reaction is allowed to proceed for 30 min at ambient temperature, quenched with a solution of sodium bisulfite (300 mg/mL). Deprotection of 73 (Step 71) is achieved by using 1 mL of 4 N HCl at 115°C for 15 min and then the aqueous solution is passed through an ion-retardation 20 resin (AG 11A8 50-100 mesh).

Example 10:    [<sup>123</sup>I]-2-Amino-2-methyl-4-(E)-iodobut-3-en-1-oic acid

2-t-Butyl carbamate-2-methyl-3-carbomethoxy propanol 75

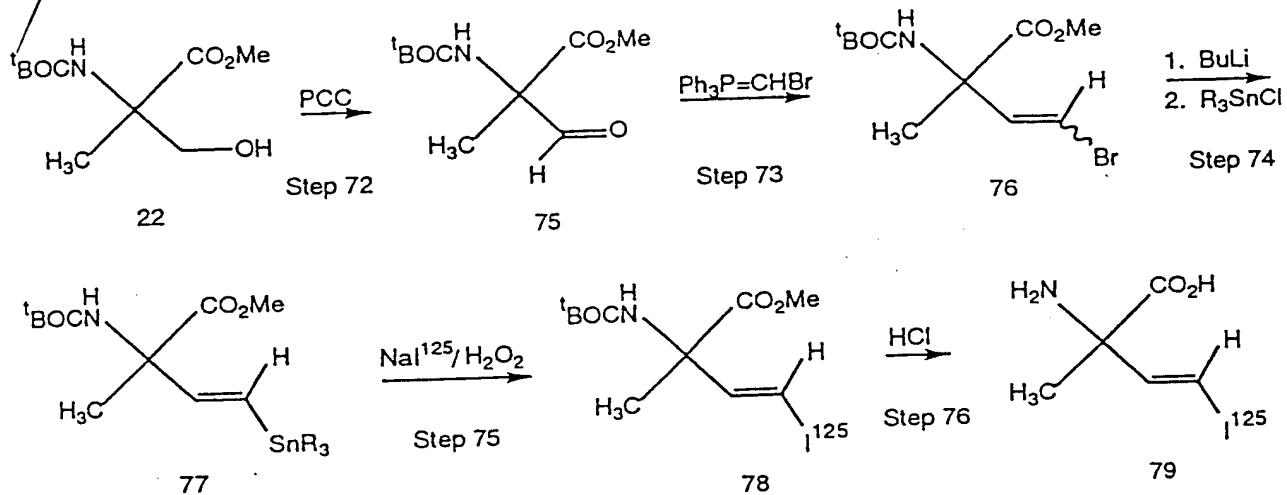
25           The protected alcohol 22 is added to a suspension of pyridinium chlorochromate in DMF at 25°C, stirred at 65°C for 3 h, and then diluted with water (75 mL) (Step 72). The mixture is extracted with ether (2x50 mL) and the combined ether layers were washed with water, dried ( $MgSO_4$ ) and the solvent removed by roto-evaporation.

2-t-Butyl carbamate-2-methyl-4-(E)-bromobut-3-en-1-oic acid methyl ester 76

35           The phosphonium salt 70 is suspended in ether and ethereal phenyllithium is added rapidly at 25°C. An orange-yellow solution results which becomes mustard yellow within 2 h. To this solution is added protected aldehyde 75 and the reaction mixture is heated

Synthesis of [123I]-2-Amino -2-methyl-4-(E)-iodobut-3-en-1-oic acid

TO410X



40

at reflux for 8 h with stirring (Step 73). The ether is removed and the residue is chromatographed on silica gel.

2-t-Butyl carbamate-2-methyl-4-(E)-tributylstannybut-3-en-1-oic acid methyl ester 77

To a solution of 76 in ether at -78°C will be added t-butyllithium (2 eq.) after 15 min tributyltin chloride is added and the mixture is warmed to 25°C (Step 74). The reaction mixture is poured into ice water and the ether layer separated and dried. The ether is removed and the residue is chromatographed on silica gel.

[<sup>123</sup>I]-2-Amino-2-methyl-4-(E)-iodobut-3-en-1-oic acid 79

Aqueous 3% hydrogen peroxide is added to a mixture of sodium [<sup>123</sup>I]iodide, tributylstannyl 77, and 0.1 N HCl in a sealed vial protected by a charcoal vent (Step 75). The reaction is allowed to proceed for 30 min at ambient temperature, quenched with a solution of sodium bisulfite (300 mg/mL). Deprotection of 78 (Step 76) is achieved by using 1 mL of 4 N HCl at 115°C for 15 min and then the aqueous solution is passed through an ion-retardation resin (AG 11A8 50-100 mesh).

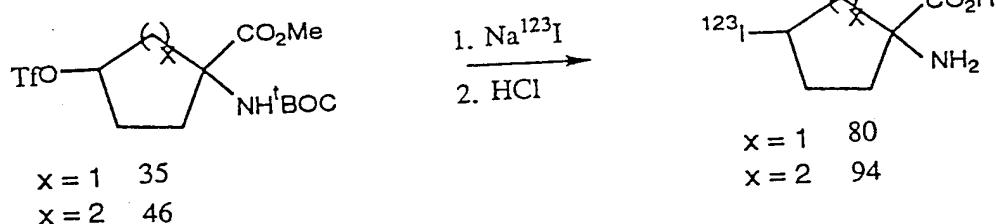
Example 11: Synthesis of [<sup>123</sup>I]-1-Amino-3-iodocyclopentane-1-carboxylic acid 80

[<sup>125</sup>I]-Sodium iodide (10 mCi, 0.1 N NaOH solution) is dried by acetonitrile (2 mL) evaporation, the protected amino acid triflate (35 (3 mg) is introduced in an acetonitrile solution (1 mL). The (NCA) iodination reaction is performed at 85°C for 5 min in a sealed vessel. Unreacted <sup>123</sup>I is removed by diluting the reacting mixture with methylene chloride followed by passage through a silica gel Seppak which gives the <sup>123</sup>I labeled product. Deprotection is achieved by using 1 mL of 4 N HCl at 115°C for 15 min and then the aqueous solution is passed through an ion-retardation resin (AG 11A8 50-100 mesh).

TO430X

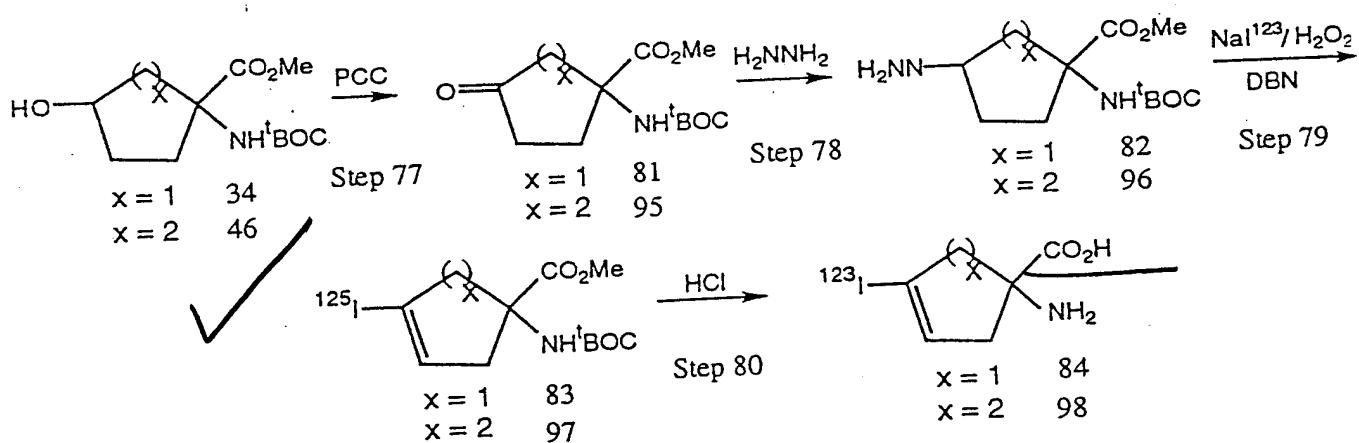
[ $^{123}\text{I}$ ]-1-Amino-3-iodocyclopentane-1-carboxylic acid  $X=1$

[ $^{123}\text{I}$ ]-1-Amino-4-iodocyclohexane-1-carboxylic acid  $X=2$



[ $^{123}\text{I}$ ]-1-Amino-3-iodocyclopentane-1-carboxylic acid  $X=1$

[ $^{123}\text{I}$ ]-1-Amino-4-iodocyclohex-2-ene-1-carboxylic acid  $X=2$



42  
43

Example 12:      Synthesis of [<sup>123</sup>I]-1-Amino-3-iodocyclopent-2-ene-1-carboxylic acid

1-t-Butyl carbamate-3-oxo-1-cyclopentane-1-carboxylic acid methyl ester **81**

5        The protected alcohol **34** will be added to a suspension of pyridinium chlorochromate in DMF at 25°C, stirred at 65°C for 3 h, and then diluted with water (75 mL) (Step 77). The mixture is extracted with ether (2x50 mL) and the combined ether layers are washed with water, dried ( $MgSO_4$ ) and the solvent removed by roto-evaporation.

10      [1-t-Butyl carbamate-1-cyclopentane-1-carboxylic acid methyl ester] 3-hydrazone **82**

15      A mixture of hydrazine, the ketone **81**, DBN, and 20 mL of ethanol is heated to boiling (Step 78). The mixture is kept hot for 10 min. The solution is cooled, and the hydrazone is collected by filtration.

20      [<sup>123</sup>I]-1-Amino-3-iodo-cyclopent-2-ene-1-carboxylic acid **84**

25      Aqueous 3% hydrogen peroxide will be added to a mixture of sodium [<sup>123</sup>I]iodide, hydrazone **82**, and 0.1 N HCl in a sealed vial protected by a charcoal vent (Step 79). The reaction is allowed to proceed for 30 min at ambient temperature, quenched with a solution of sodium bisulfite (300 mg/mL). Deprotection of **83** (Step 80) is achieved by using 1 mL of 4 N HCl at 115°C for 15 min and then the aqueous solution is passed through an ion-retardation resin (AG 11A8 50-100 mesh).

Example 13:      Synthesis of E-[<sup>123</sup>I]-1-Amino-3-(2-iodoethenyl)cyclopentane-1-carboxylic acid **88**

30      1-t-Butyl carbamate-3-bromo-1-cyclopentane-1-carboxylic acid methyl ester **85**

35      Bromine is added to a mixture of alcohol **34** and triphenylphosphine in DMF at -10°C (Step 81). After stirring for 1 h, the mixture is diluted with water and extracted with ether. The ether layer is washed with water, 10% sodium sulfite, and then

43  
CH4

dried. The ether is removed and the residue is chromatographed on silica gel.

5           1-t-Butyl carbamate-3-ethynyl-1-cyclopentane-1-carboxylic acid  
methyl ester **86**

10          The bromo compound **85** in THF is added to a suspension of lithium acetylide ethylenediamine complex in THF stirred at 0°C under a nitrogen atmosphere (Step 82). The mixture is stirred for 3 h at 25°C, poured into ice water, and extracted with ether. The ether extract is washed with ice cold 1 N HCl, brine and then dried. The ether is removed and the residue is chromatographed on silica gel.

15          1-t-Butyl carbamate-3-((E)-2-tributylstannylethenyl)-1-cyclopentane-1-carboxylic acid methyl ester **87**

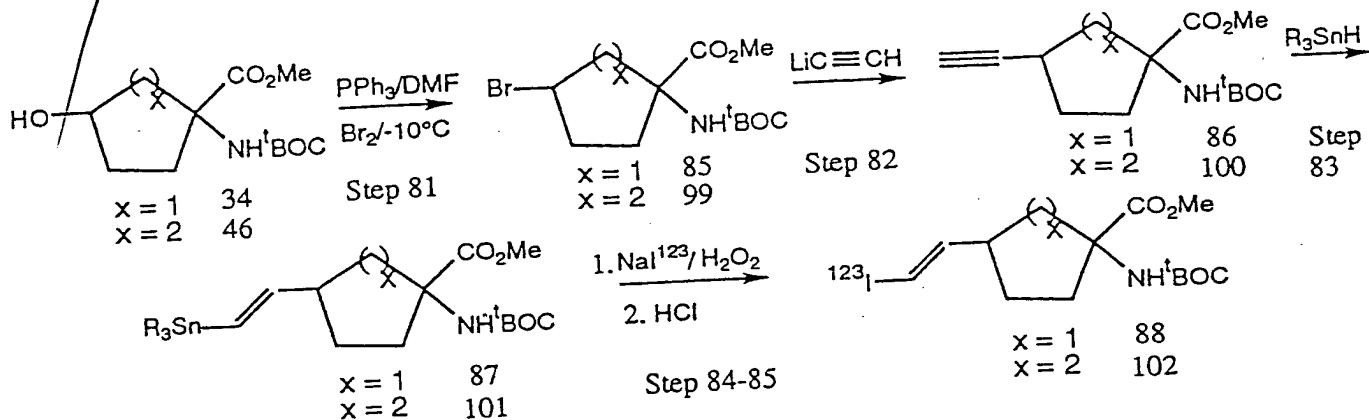
20          Tributyltin hydride, the alkyne **86** and azobisisobutyronitrile will be refluxed in toluene under nitrogen atmosphere for 10 h (Step 83). The reaction mixture is cooled, solvent removed *in vacuo*, and the residue chromatographed on silica gel.

25          [<sup>123</sup>I]-1-Amino-3-((E)-2-iodoethenyl)cyclopentane-1-carboxylic acid  
**88**

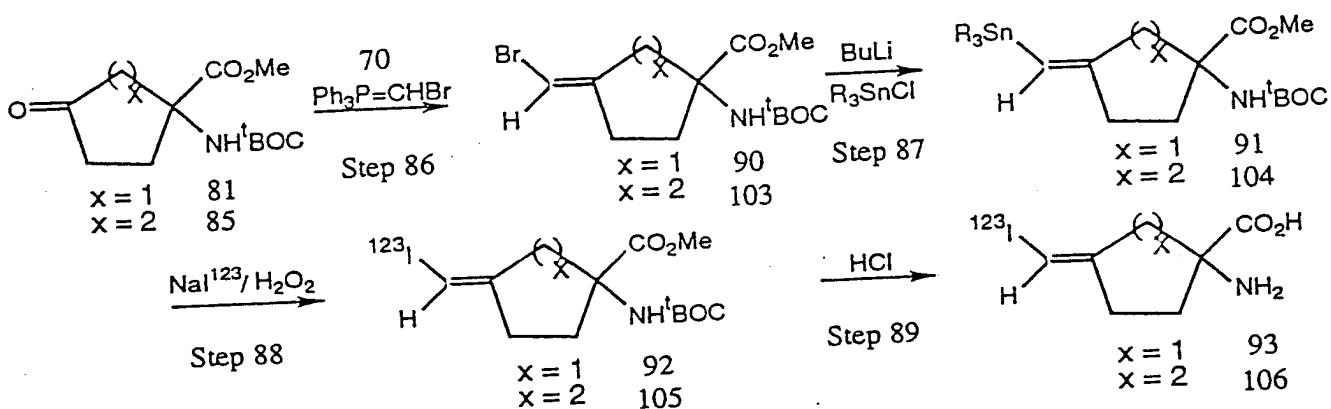
30          Aqueous 3% hydrogen peroxide is added to a mixture of sodium [<sup>123</sup>I]iodide, tributylstannyl **87**, and 0.1 N HCl in a sealed vial protected by a charcoal vent (Step 84). The reaction is allowed to proceed for 30 min at ambient temperature, quenched with a solution of sodium bisulfite (300 mg/mL). Deprotection (Step 85) is achieved by using 1 mL of 4 N HCl at 115°C for 15 min and then the aqueous solution is passed through an ion-retardation resin (AG 11A8 50-100 mesh).

E-[123I]-1-Amino-4-(2-iodoethyl)cyclopentane-1-carboxylic acid X=1  
E-[123I]-1-Amino-4-(2-iodoethyl)cyclohexane-1-carboxylic acid X=2

TO460X



[123I]-Amino-3-(iodomethylenyl)cyclopentane-1-carboxylic acid X=1  
[123I]-1-Amino-4-(iodomethylenyl)cyclohexane-1-carboxylic acid X=2  
[123I]-1-Amino-4-(iodomethylenyl)cyclohexane-1-carboxylic acid X=2



45  
46

Example 14: Synthesis of [<sup>123</sup>I]-1-Amino-3-(iodomethylenyl)cyclopentane-1-carboxylic acid 93

1-t-Butyl carbamate-3-(bromomethylenyl)-1-cyclopentane-1-carboxylic acid methyl ester 90

5 The phosphonium salt 70 is suspended in ether and ethereal phenyllithium is added rapidly at 25°C. An orange-yellow solution results which becomes mustard yellow within 2 h. To this solution is added protected ketone 81 and the reaction mixture is heated at reflux for 8 h with stirring (Step 86). The ether is removed and the residue is chromatographed on silica gel.

10 1-t-Butyl carbamate-3-(tributylstannylmethylenyl)-1-cyclopentane-1-carboxylic acid methyl ester 91

15 To a solution of 90 in ether at -78°C is added t-butyllithium (2 eq.) after 15 min tributyltin chloride is added and the mixture is warmed to 25°C (Step 87). The reaction mixture is poured into ice water and the ether layer separated and dried. The ether is removed and the residue is chromatographed on silica gel.

20 [<sup>123</sup>I]-1-Amino-3-(iodomethylenyl)cyclopentane-1-carboxylic acid 93

Aqueous 3% hydrogen peroxide is added to a mixture of sodium [<sup>123</sup>I]iodide, tributylstannyl 91, and 0.1 N HCl in a sealed vial protected by a charcoal vent (Step 88). The reaction is allowed to proceed for 30 min at ambient temperature, quenched with a solution of sodium bisulfite (300 mg/mL). Deprotection of 92 (Step 89) is achieved by using 1 mL of 4 N HCl at 115°C for 15 min and then the aqueous solution is passed through an ion-retardation resin (AG 11A8 50-100 mesh).

30 Example 15: Synthesis of [<sup>123</sup>I]-1-Amino-4-iodocyclohexane-1-carboxylic acid 94

[<sup>123</sup>I]-Sodium iodide (10 mCi, 0.1 N NaOH solution) will be dried by acetonitrile (2 mL) evaporation, the protected amino acid triflate 46 (3 mg) is introduced in an acetonitrile solution (1 mL). The (NCA) iodination reaction is performed at 85°C for 5 min in a sealed vessel. Unreacted <sup>123</sup>I is removed by diluting the

reacting mixture with methylene chloride followed by passage through a silica gel Seppak which gives the  $^{123}\text{I}$  labeled product. Deprotection is achieved by using 1 mL of 4 N HCl at 115°C for 15 min and then the aqueous solution is passed through an ion-retardation resin (AG 11A8 50-100 mesh).

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Example 16: Synthesis of  $[^{123}\text{I}]$ -1-Amino-4-iodocyclohex-2-ene-1-carboxylic acid

10  $[1\text{-t-Butyl carbamate-4-oxo-1-cyclohexane-1-carboxylic acid methyl ester } \mathbf{95}]$

The protected alcohol  $\mathbf{46}$  is added to a suspension of

pyridinium chlorochromate in DMF at 25°C, stirred at 65°C for 3 h, and then diluted with water (75 mL) (Step 77). The mixture is extracted with ether (2x50 mL) and the combined ether layers are washed with water, dried ( $\text{MgSO}_4$ ) and the solvent removed by rotovaporation.

15

$[1\text{-t-Butyl carbamate-1-cyclohexane-1-carboxylic acid methyl ester}]$   
 $4\text{-hydrazone } \mathbf{96}.$

20 A mixture of hydrazine, the ketone  $\mathbf{95}$ , and 20 mL of ethanol is heated to boiling, and a drop of glacial acetic acid is added. The mixture is kept hot for 10 min (Step 78). The solution is cooled, and the hydrazone is collected by filtration.

25  $[^{123}\text{I}]$ -1-Amino-4-iodo-cyclohex-2-ene-1-carboxylic acid  $\mathbf{98}$   
Aqueous 3% hydrogen peroxide is added to a mixture of sodium  $^{125}\text{I}$  iodide, hydrazone  $\mathbf{96}$ , and 0.1 N HCl in a sealed vial protected by a charcoal vent (Step 79). The reaction is allowed to proceed for 30 min at ambient temperature, quenched with a solution of sodium bisulfite (300 mg/mL). Deprotection of  $\mathbf{97}$  (Step 80) is achieved by using 1 mL of 4 N HCl at 115°C for 15 min and then the aqueous solution is passed through an ion-retardation resin (AG 11A8 50-100 mesh).

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AS

Example 17: Synthesis of E-[<sup>123</sup>I]-1-Amino-3-(2-iodoethenyl)cyclohexane-1-carboxylic acid

1-t-Butyl carbamate-4-bromo-1-cyclohexane-1-carboxylic acid methyl ester **99**

5        Bromine is added to a mixture of alcohol **46** and triphenylphosphine in DMF at -10°C (Step 81). After stirring for 1 h, the mixture is diluted with water and extracted with ether. The ether layer is washed with water, 10% sodium sulfite, and then dried. The ether is removed and the residue is chromatographed on 10 silica gel.

1-t-Butyl carbamate-4-ethynyl-1-cyclohexane-1-carboxylic acid methyl ester **100**

15       The bromo compound **99** in THF is added to a suspension of lithium acetylide ethylenediamine complex in THF stirred at 0°C under a nitrogen atmosphere (Step 82). The mixture is stirred for 3 h at 25°C, poured into ice water, and extracted with ether. The ether extract is washed with ice cold 1 N HCl, brine and then dried. The ether is removed and the residue is chromatographed on 20 silica gel.

1-t-Butyl carbamate-4-((E)-2-tributylstannylethenyl)-1-cyclohexane-1-carboxylic acid methyl ester **101**

25       Tributyltin hydride, the alkyne **100** and azobisisobutyronitrile are refluxed in toluene under nitrogen atmosphere for 10 h (Step 83). The reaction mixture is cooled, solvent removed in vacuo, and the residue chromatographed on 30 silica gel.

[<sup>123</sup>I]-1-Amino-4-((E)-2-iodoethenyl)cyclohexane-1-carboxylic acid

**102**

35       Aqueous 3% hydrogen peroxide is added to a mixture of sodium [<sup>123</sup>I]iodide, tributylstannyl **101**, and 0.1 N HCl in a sealed vial protected by a charcoal vent (Step 84). The reaction is allowed to proceed for 30 min at ambient temperature, quenched with a solution of sodium bisulfite (300 mg/mL). Deprotection (Step 85) is achieved by using 1 mL of 4 N HCl at 115°C for 15 min and then

the aqueous solution is passed through an ion-retardation resin (AG 11A8 50-100 mesh).

Example 18: Synthesis of [<sup>123</sup>I]-1-Amino-4-(iodomethylenyl)cyclohexane-1-carboxylic acid 1-t-Butyl carbamate-4-(bromomethylenyl)-1-cyclohexane-1-carboxylic acid methyl ester 103

The phosphonium salt **70** is suspended in ether and ethereal phenyllithium is added rapidly at 25°C. An orange-yellow solution results which becomes mustard yellow within 2 h. To this solution is added protected ketone **95** and the reaction mixture is heated at reflux for 8 h with stirring (Step 86). The ether is removed and the residue is chromatographed on silica gel.

15 1-t-Butyl carbamate-4-(tributylstannylmethylenyl)-1-cyclohexane-1-carboxylic acid methyl ester 104  
was added t-

To a solution of 103 in ether at -78°C is added t-butyllithium (2 eq.) after 15 min tributyltin chloride is added and the mixture is warmed to 25°C (Step 87). The reaction mixture is poured into ice water and the ether layer separated and dried. The ether is removed and the residue is chromatographed on silica gel.

[<sup>123</sup>I]-1-Amino-4-(iodomethylene)cyclohexane-1-carboxylic acid **106**  
 Aqueous 3% hydrogen peroxide will be added to a mixture of sodium [<sup>125</sup>I]iodide, tributylstannyl **104**, and 0.1 N HCl in a sealed vial protected by a charcoal vent (Step 88). The reaction is allowed to proceed for 30 min at ambient temperature, quenched with a solution of sodium bisulfite (300 mg/mL). Deprotection of **105** (Step 89) is achieved by using 1 mL of 4 N HCl at 115°C for 15 min and then the aqueous solution is passed through an ion-retardation resin (AG 11A8 50-100 mesh).

Example 19: Biodistribution Studies in Tumor Bearing Rats

The distribution of radioactivity expressed as percent dose per gram in tissues of unfasted male fisher rats with implanted gliosarcoma at 5 min and 60 min after intravenous administration

of [<sup>18</sup>F]FACBC is shown in Table I. The initial level of accumulation of radioactivity in the brain after injection of [<sup>18</sup>F]FACBC was low (0.11% dose/gram) at 5 min and increased slightly to 0.26% dose/gram. The agent, however, exhibited a high uptake in the brain tumor. The tumor uptake exhibited a maximum at 60 min (1.72% dose/gram) resulting in an increase in the tumor to brain ratio of 5.58 at 5 min to 6.61 at 60 min. The bone radioactivity showed no increase from 0.52% dose/gram at 5 min, to 0.38% dose/gram at 60 min, which demonstrates the expected stability of the 2-cyclobutyl group to significant *in vivo* defluorination.

We compared the tumor uptake of [<sup>18</sup>F]FACBC with [<sup>18</sup>F]2-FDG in a separate group of male fisher rats with implanted gliosarcoma at 5 min and 60 min after intravenous administration of [<sup>18</sup>F]2-FDG the initial level of accumulation of radioactivity in the brain tumor after injection of [<sup>18</sup>F]2-FDG was good, 1.29% dose/gram. The 2-FDG, however, exhibited a decrease in uptake in the brain tumor to 1.05% dose/gram at 60 min. The decrease of radioactivity in the tumor at 60 min in conjunction with initial high brain uptake and retention resulted in a low tumor to brain ratio of 0.84 at 60 min.

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S/

TABLE I

Distribution of Radioactivity in Tissues of Unfasted Male Fisher Rats following Intravenous Administration of [<sup>18</sup>F]FACBC

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	Mean % Injected Dose/Gram (Average of 4 Rats)	
Organ	5 min	60 min
Blood	0.58	0.32
Heart	0.70	0.56
Muscle	0.27	0.41
Lung	1.13	0.64
Kidney	1.08	0.60
Spleen	1.55	0.68
Liver	1.10	1.70
Testis	0.25	0.28
Bone	0.52	0.38
Brain (B)	0.11	0.26
Tumor (T)	0.61	1.72
T/B	5.58	6.61

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This significant tumor to brain ratio of 6.6 at 60 min strongly supports the use of [<sup>18</sup>F]FACBC as a valuable imaging agent for the diagnosis and management of treatment of metastatic disease in humans by PET.

In addition [<sup>18</sup>F]FACBC displayed highly specific binding to human astrocyte tumor cells in a human patient, further establishing the suitability of At-labelled compounds of the invention for therapy.

Example 20:

Synthesis of [Tc-99m] technetium. [3-(1-(5-mercaptopent-1-ynyl))-1-aminocyclobutane-1-carboxylic acid)][2,2'-methylimino]bis[ethanethiolato](2-)N,S,S']oxo 114

5 1-t-Butyl carbamate-3-(5-chloropent-1-ynyl)cyclobutane-1-carboxylic acid methyl ester 107

5-Chloropent-1-yne is cooled to -78°C and treated with one equivalent of n-butyllithium. 1-t-Butyl carbamate-3-(trifluoromethane sulfonoxymethyl)-cyclobutane-1-carboxylic acid methyl ester (11) is added to the resultant lithium acetylide, the mixture is allowed to warm to room temperature, poured onto ice and extracted with ether. The solvent is removed and the product is purified by column chromatography (silica gel).

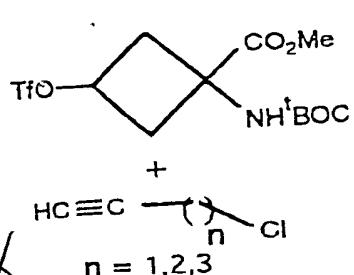
15 1-t-Butyl carbamate-3-(1-(5-mercaptopent-1-ynyl))cyclobutane-1-carboxylic acid methyl ester 110

Thiourea and 1-t-butyl carbamate-3-(5-chloropent-1-ynyl)cyclobutane-1-carboxylic acid methyl ester (107) are heated together at 80°C in DMF for one hour. The reaction intermediate is hydrolyzed by warming to 50°C with 3 M aqueous hydroxide. The mixture is neutralized with dilute HCl, extracted with ether and the combined ether extract is washed with brine and dried ( $MgSO_4$ ). Solvent is removed to give the mercaptan product 110.

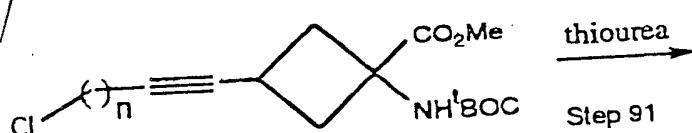
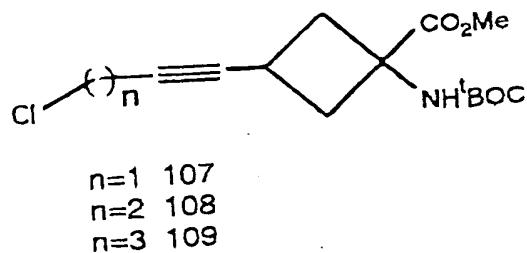
25 [Tc-99m] Technetium, [3-(1-(5-mercaptopent-1-ynyl))-1-aminocyclobutane-1-carboxylic acid)][2,2'-methylimino]bis[ethanethiolato](2-)N,S,S']oxo 114

The complex is prepared by combining  $^{99m}TcO_4$ -eluate and equimolar amounts of N-di(2-ethylmercapto)methylamine and 1-t-butyl carbamate-3-(5-mercaptopent-1-ynyl)cyclobutane-1-carboxylic acid methyl ester (110). The mixture is applied to a C-18 Seppak and eluted with 0.5 mL of water and the 0.5 mL ethanol to obtain the protected [99mTc] amino acid. This compound is hydrolyzed with 3 N HCl at 120°C for 20 min and then purified by passage through AG11-8A ion retardation resin.

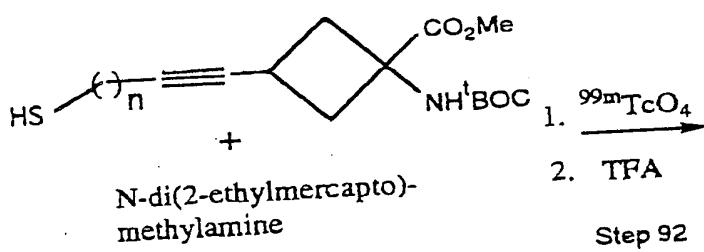
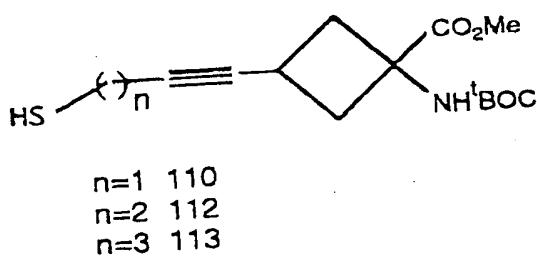
[Tc-99m] technetium, [3-(1-(5-mercaptopent-1-ynyl))-1-aminocyclobutane-1-carboxylic acid)][2,2'-methylenimino]bis[ethanethiolato]](2)-N,S,S'oxo



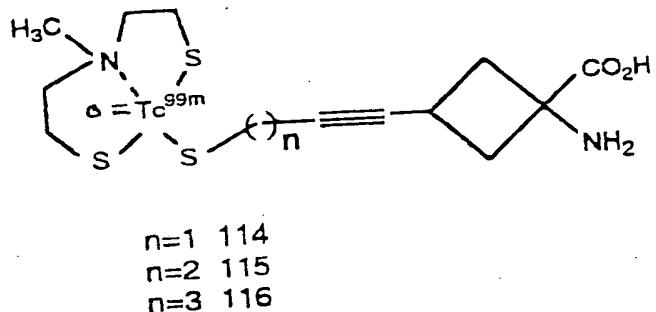
n-butyllithium  
Step 90



thiourea  
Step 91



Step 92



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S4

Example 21: Synthesis of [Tc-99m] technetium, [3-(1-(5-mercaptopent-1(Z)-enyl))-1-aminocyclobutane-1-carboxylic acid][2,2'-methylimino)bis[ethanethiolato]](2-)N,S,S']oxo 123

5 1-t-Butyl carbamate-3-(1-(5-chloropent-1(Z)-enyl))-cyclobutane-1-carboxylic acid methyl ester 117

A mixture of 1-t-butyl carbamate-3-(1-5-chloropent-1-ynyl)cyclobutane-1-carboxylic acid methyl ester (107), palladium on barium sulfate, quinoline and methanol are shaken under 10 hydrogen for 8 h. The catalyst is removed by filtration through Celite and washed with methanol. The filtrate is concentrated under reduced pressure to give the cis-alkene compound 120.

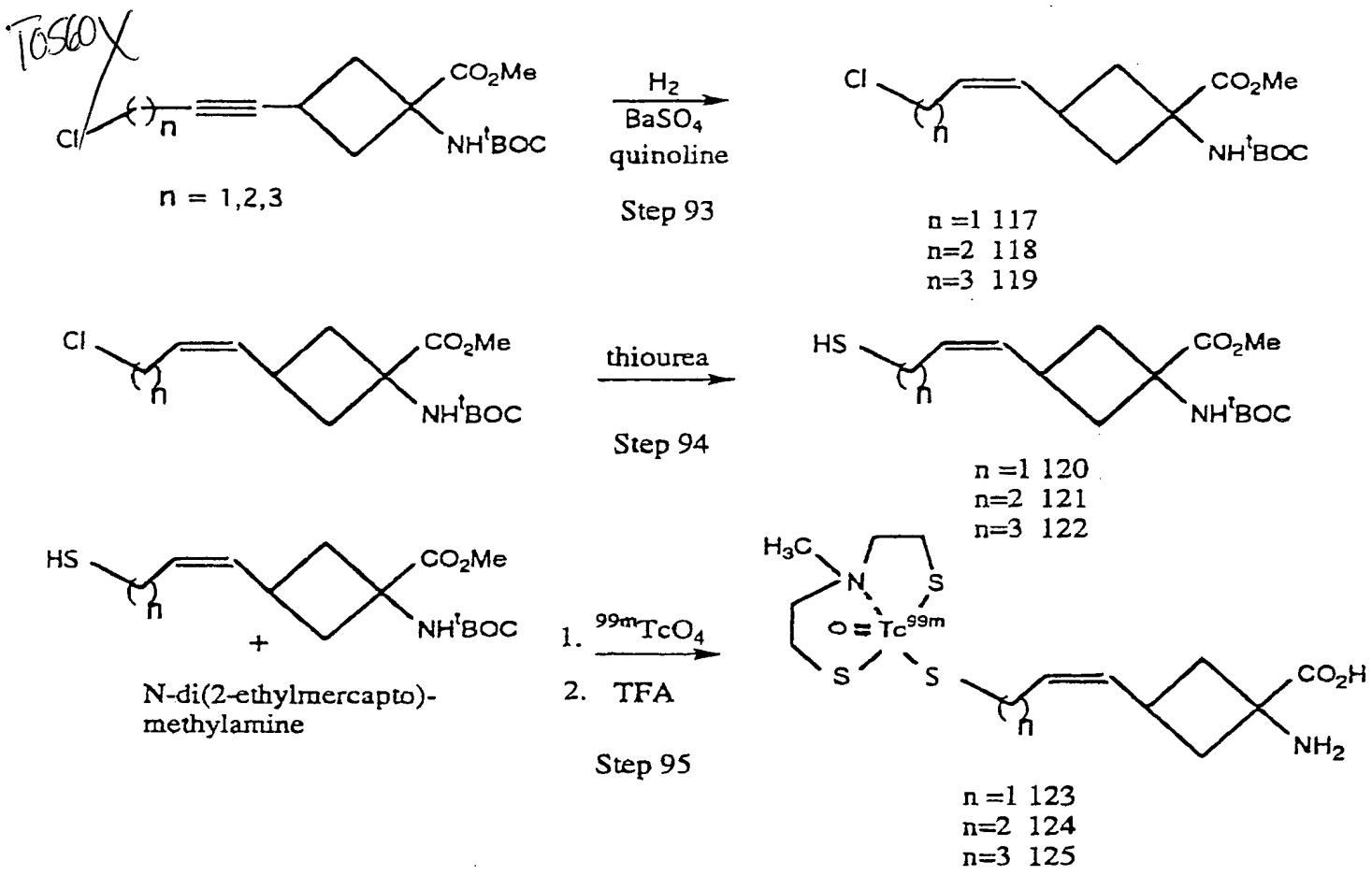
15 1-t-Butyl carbamate-3-(1-(5-mercaptopent-1(Z)-enyl))-cyclobutane-1-carboxylic acid methyl ester 117

Thiourea and 1-t-butyl carbamate-3-(1-5-chloropent-1(Z)-enyl)-cyclobutane-1-carboxylic acid methyl ester (117) are heated together at 80°C in DMF for one hour. The reaction intermediate is hydrolyzed by warming to 50°C with 3 M aqueous hydroxide. The 20 mixture is neutralized with dilute HCl, extracted with ether and the combined ether extract is washed with brine and dried ( $MgSO_4$ ). Solvent is removed to give the mercaptan product 120.

25 [Tc-99m] Technetium, [3-(1-(5-mercaptopent-1(Z)-enyl))-1-aminocyclobutane-1-carboxylic acid)][2,2'-methyl-imino)bis[ethanethiolato]](2-)N,S,S']oxo 123

The complex is prepared by combining  $^{99m}TcO_4$ -eluate and equimolar amounts of N-di(2-ethylmercapto)methylamine and 1-t-butyl carbamate-3-(1-(5-mercaptopent-1(Z)-enyl))cyclobutane-1-carboxylic acid methyl ester (120). The mixture is applied to a C-18 Seppak and eluted with 0.5 mL of water and then 0.5 mL ethanol to obtain the protected [99mTc] amino acid. This compound is hydrolyzed with trifluoroacetic acid (TFA) at 25°C for 5 min and then purified by passage through AG11-8A ion retardation 35 resin.

[Tc-99m] Technetium, [3-(1-(5-mercaptopent-1(Z)-enyl))-1-aminocyclobutane-1-carboxylic acid)][2,2'-methyl-imino)bis[ethanethiolato]](2-)N,S,S']oxo



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Example 22:

Synthesis of [Tc-99m] technetium, [3-(5-(1-pentanethiol))-1-aminocyclobutane-1-carboxylic acid)][2,2'-methylimino)bis[ethanethiolato]](2)-N,S,S' ]oxo 132

5 1-t-Butyl carbamate-3-(5-(1-chloropentyl))-cyclobutane-1-carboxylic acid methyl ester 126

A mixture of 1-t-butyl carbamate-3-(1-(5-chloropent-1-ynyl))cyclobutane-1-carboxylic acid methyl ester (107), Raney Ni and methanol are shaken under hydrogen for 8 h. The catalyst is removed by filtration through Celite and washed with methanol. The filtrate is concentrated under reduced pressure to give the saturated chloroalkane compound 126. The solvent is removed and the product is purified by column chromatography (silicia gel).

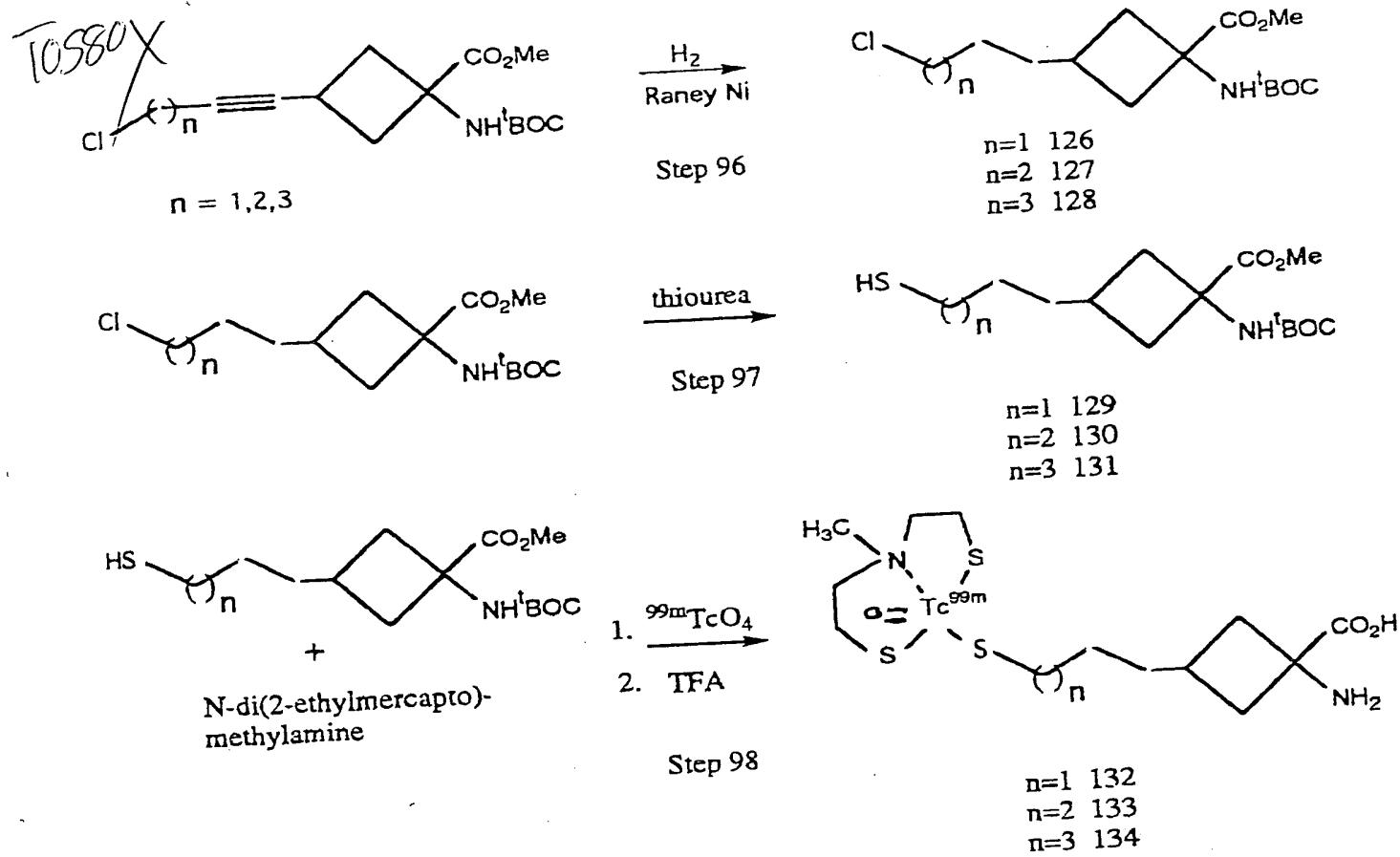
15 1-t-Butyl carbamate-3-(5-(1-pentanethiol))cyclobutane-1-carboxylic acid methyl ester 129

Thiourea and 1-t-butyl carbamate-3-(1-5-chloropent-1(Z)-enyl))-cyclobutane-1-carboxylic acid methyl ester (126) are heated together at 80°C in DMF for one hour. The reaction intermediate is hydrolyzed by warming to 50°C with 3 M aqueous hydroxide. The mixture is neutralized with dilute HCl, extracted with ether and the combined ether extract is washed with brine and dried ( $MgSO_4$ ). Solvent is removed to give the mercaptan product 129.

25 [Tc-99m] Technetium, [3-(5-(1-pentanethiol))-1-aminocyclobutane-1-carboxylic acid)][2,2'-methyl-imino)bis[ethanethiolato]](2)-N,S,S' ]oxo 132

The complex is prepared by combining  $^{99m}TcO_4$ -eluate and equimolar amounts of N-di(2-ethylmercapto)methylamine and 1-t-butyl carbamate-3-(5-(1-pentanethiol))cyclobutane-1-carboxylic acid methyl ester (129). The mixture is applied to a C-18 Seppak and eluted with 0.5 mL of water and then 0.5 mL ethanol to obtain the protected [99mTc] amino acid. This compound is hydrolyzed with TFA at 25°C for 5 min and then purified by passage through AG11-8A ion retardation resin.

[Tc-99m] Technetium, [3-(5-(1-pentanethiol))-1-aminocyclobutane-1-carboxylic acid)][2,2'-methyl-imino]bis[ethanethiolato]](2-)N,S,S]oxo



Example 23: Synthesis of [Tc-99m] technetium, [3-(1-(5-mercaptopent-1(E)-enyl))-1-aminocyclobutane-1-carboxylic acid)][2,2'-methylimino)bis[ethanethiolato]](2)-N,S,S'oxo 141

5 1-t-Butyl carbamate-3-(1-(5-chloropent-1(E)-enyl))cyclobutane-1-carboxylic acid methyl ester 135

10 5-Chloro-1(E)-iodopent-1-ene in ether is cooled to -78°C and treated with n-butyllithium. After stirring for one hour, 1-t-butyl carbamate-3-(trifluoromethane sulfonylmethyl)-cyclobutane-1-carboxylic acid methyl ester (11) is added to the lithium alkynylide over a 15 min period. The mixture is stirred at 25°C for 1 h poured into ice cold aqueous 5% HCl and extracted with ether. The solvent is removed and the product is purified by column chromatography (silica gel).

15 1-t-Butyl carbamate-3-(1-(5-mercaptopent-1(E)-enyl))cyclobutane-1-carboxylic acid methyl ester 138

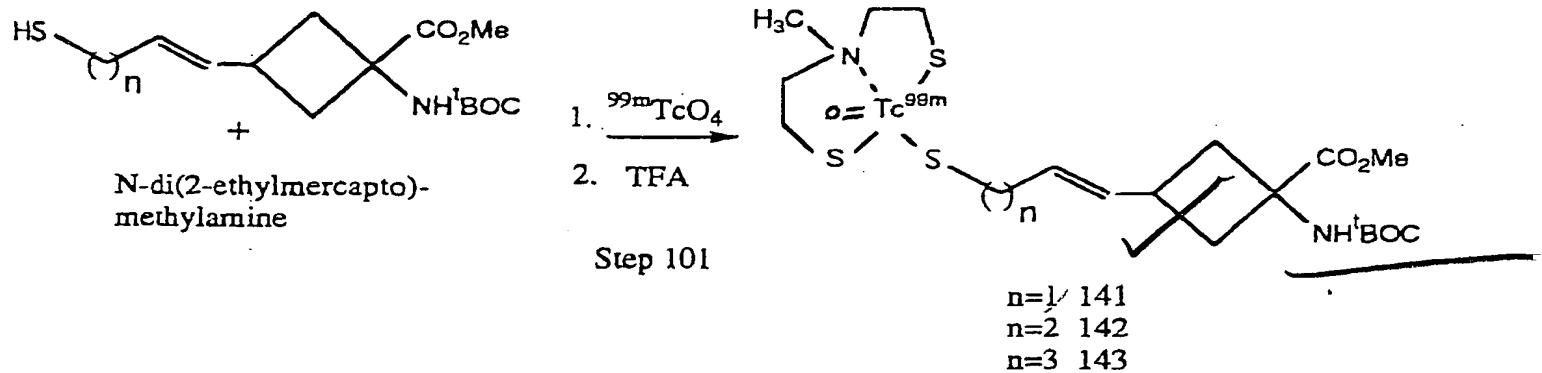
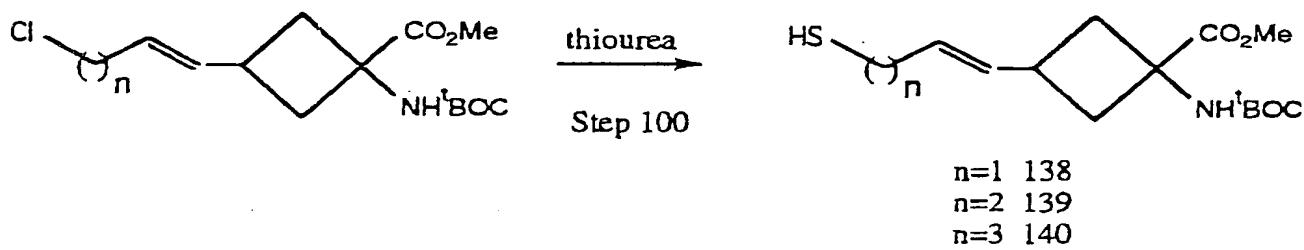
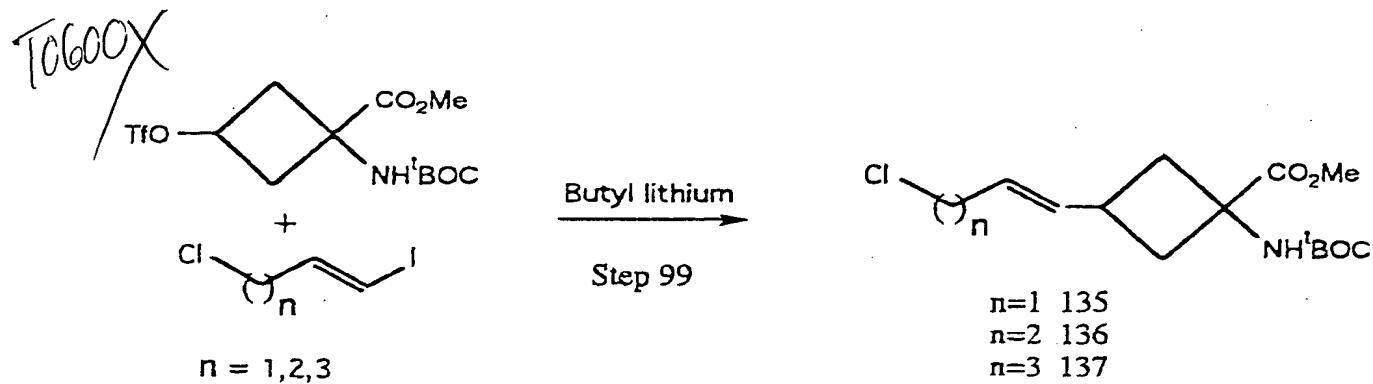
20 Thiourea and 1-t-butyl carbamate-3-(1-(5-chloropent-1(E)-enyl))-cyclobutane-1-carboxylic acid methyl ester (135) are heated together at 80°C in DMF for one hour. The reaction intermediate is hydrolyzed by warming to 50°C with 3 M aqueous hydroxide. The mixture is neutralized with dilute HCl, extracted with ether and the combined ether extract is washed with brine and dried ( $MgSO_4$ ). Solvent is removed to give the mercaptan product 138.

25 [Tc-99m] technetium, [3-(1-(5-mercaptopent-1(E)-enyl))-1-aminocyclobutane-1-carboxylic acid)][2,2'-methylimino)bis[ethanethiolato]](2)-N,S,S'oxo 141

30 The complex is prepared by combining  $^{99m}TcO_4$ -eluate and equimolar amounts of N-di(2-ethylmercapto)methylamine and 1-t-butyl carbamate-3-(1-(5-mercaptopent-1(E)-enyl))cyclobutane-1-carboxylic acid methyl ester (138). The mixture is applied to a C-18 Seppak and eluted with 0.5 mL of water and then 0.5 mL ethanol to obtain the protected [99mTc] amino acid. This compound is hydrolyzed with TFA at 25°C for 5 min and then purified by passage through AG11-8A ion retardation resin.

SG  
58

[Tc-99m] technetium, [3-(1-(5-mercaptopent-1(E)-enyl))-1-aminocyclobutane-1-carboxylic acid)][2,2'-methyl-imino)bis(ethanethiolato)](2-)N,S,S'oxo



Example 24:

Synthesis of [<sup>99m</sup>Tc] technetium, [3-(1-(5-aminopent-1-ynyl))-1-aminocyclobutane-1-carboxylic acid)carbonyl cyclopentadienyl][tricarbonyl] **150**  
1-t-Butyl carbamate-3-(1-(5-aminopent-1-ynyl))cyclobutane-1-  
carboxylic acid methyl ester **144**

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General procedure:

1-t-Butyl carbamate-3-(1-(5-aminopent-1-ynyl))cyclobutane-1-carboxylic acid methyl ester (**107**) is reacted with sodium azide in DMF at 80°C. The mixture is quenched with water and extracted with ether to afford the azide. The crude azide product is dissolved in methanol and treated with sodium borohydride and quenched with cold 1 M HCl. The mixture is brought to a pH of 8 and extracted with ether to give the amine product **144**.

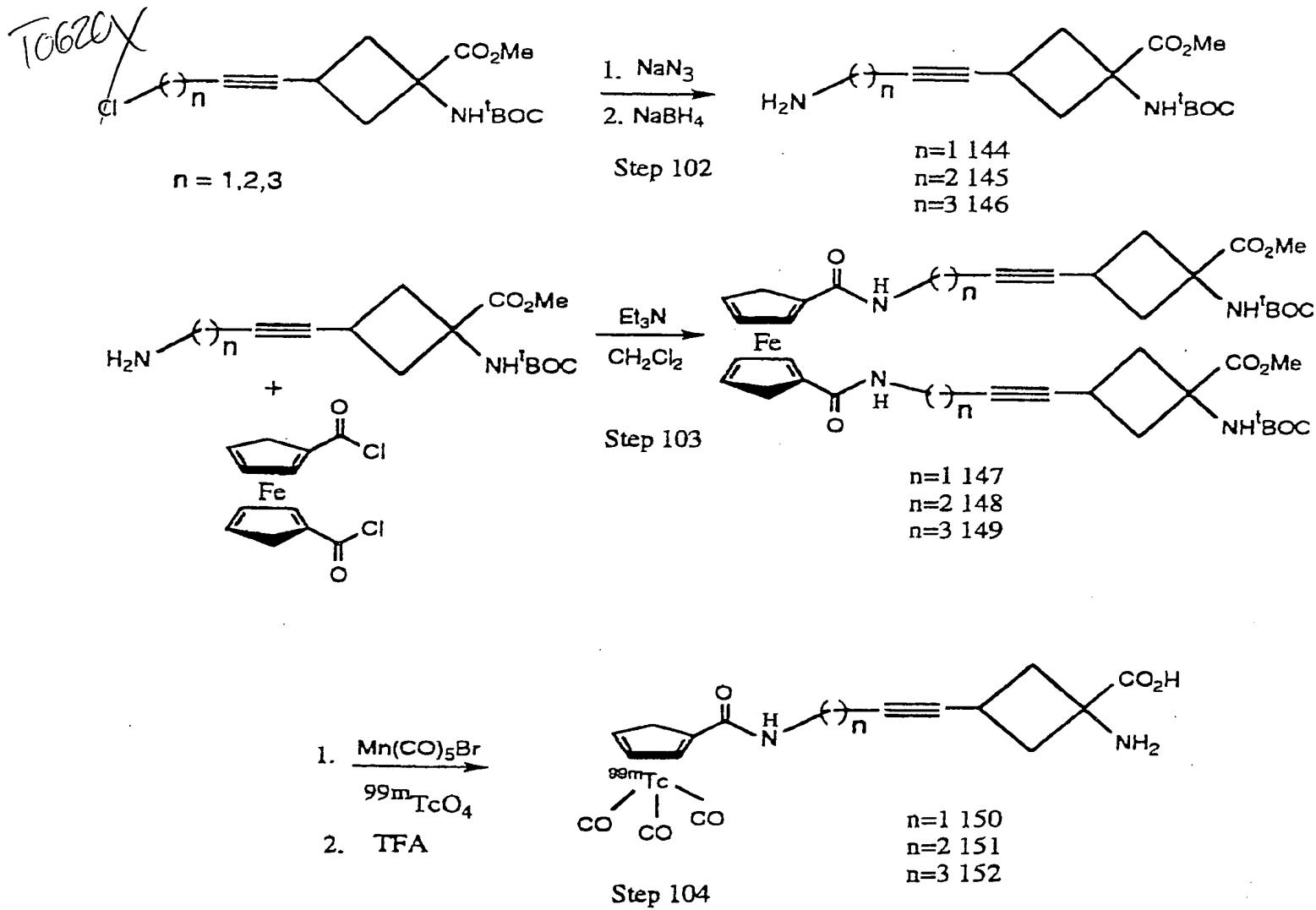
15 [<sup>99m</sup>Tc] Technetium, [3-(1-(5-aminopent-1-ynyl))-1-aminocyclobutane-1-carboxylic acid)carbonyl cyclopentadienyl][tricarbonyl] **150**

General procedure:

A solution of ferrocenedicarbonyl chloride, the amino compound **144** and triethylamine in dry methylene chloride are heated at reflux for 2 h. The solution is extracted methylene chloride, washed with saturated sodium bicarbonate and evaporated to dryness.

The ferrocene compound **147** and Mn(CO)<sub>5</sub>Br are placed in a glass tube, and THF and <sup>99m</sup>TcO<sub>4</sub>-eluate are added. The glass tube is sealed and heated at 150°C for 1 h. The mixture is applied to a C-18 Seppak and eluted with 0.5 mL of water and then 0.5 mL ethanol to obtain the protected [<sup>99m</sup>Tc] amino acid. This compound is hydrolyzed with TFA at 25°C for 5 min and then purified by passage through AG11-8A ion retardation resin.

[<sup>99m</sup>Tc] Technetium, [3-(1-(5-aminopent-1-ynyl))-1-aminocyclobutane-1-carboxylic acid)carbonyl cyclopentadienyl][tricarbonyl]



Example 25:

Synthesis of [99mTc] technetium, [3-(1-(5-aminopent-1(Z)-enyl))-1-aminocyclobutane-1-carboxylic acid)carbonyl cyclopentadienyl][tricarbonyl] 159

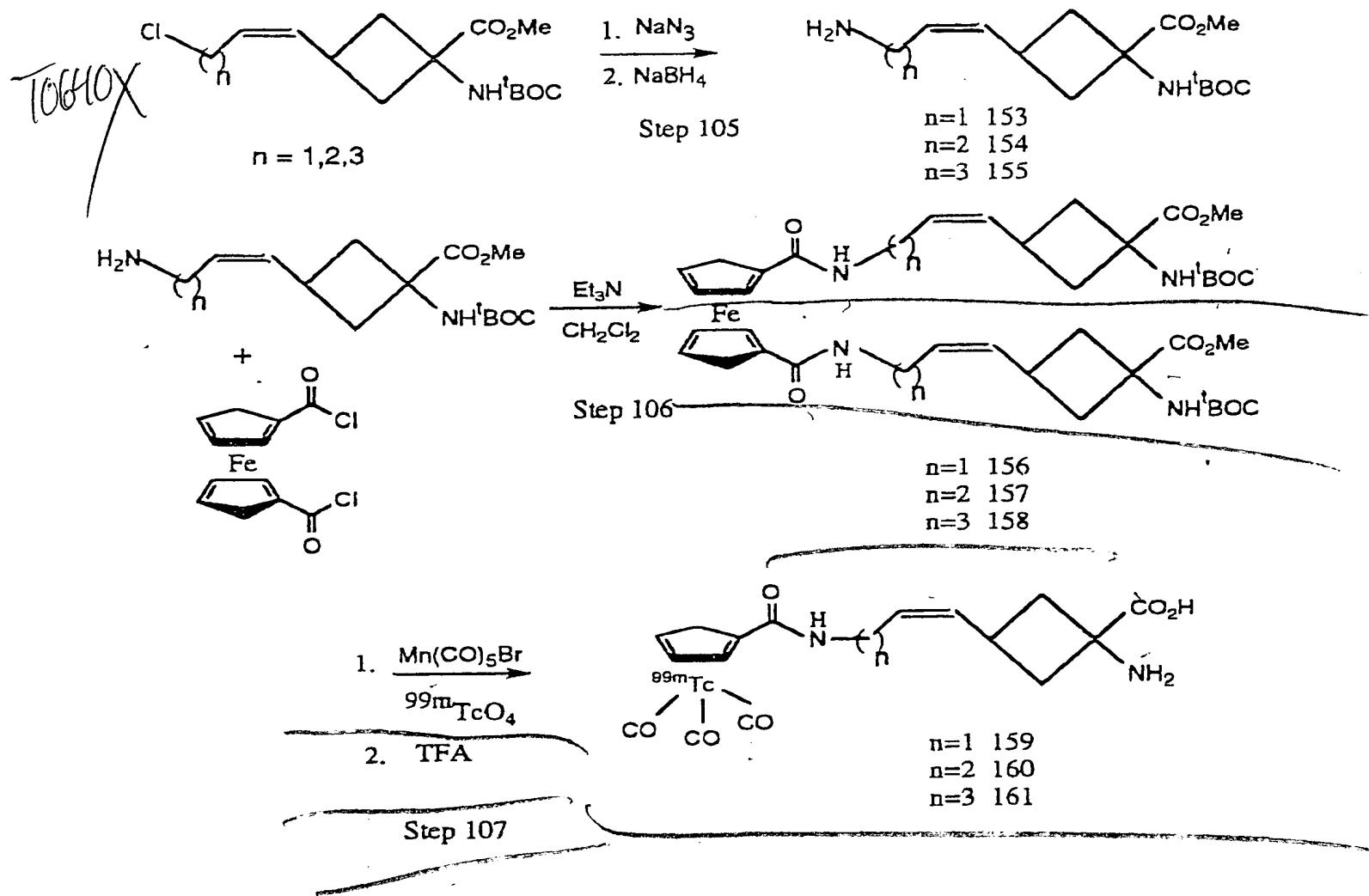
5 1-t-Butyl carbamate-3-(1-(5-aminopent-1(Z)-enyl)-cyclobutane-1-carboxylic acid methyl ester 153

The above procedure for 144 is followed using 1-t-butyl carbamate-3-(1-(5-aminopent-1(Z)-enyl)cyclobutane-1-carboxylic acid methyl ester (144)

10 [99mTc] Technetium, [3-(1-(5-aminopent-1(Z)-enyl))-1-aminocyclobutane-1-carboxylic acid)carbonyl cyclopentadienyl][tricarbonyl] 159

15 The above procedure for 150 is followed using 1-t-butyl carbamate-3-(1-(5-aminopent-1(Z)-enyl-cyclobutane-1-carboxylic acid methyl ester (153) as the amino compound.

[ $^{99m}\text{Tc}$ ] technetium, [3-(1-(5-aminopent-1(Z)-enyl))-1-aminocyclobutane-1-carboxylic acid)carbonyl cyclopentadienyl][tricarbonyl]



63  
64

Example 26:

Synthesis of [99mTc] technetium. [3-(1-(5-pentaneamine))-1-aminocyclobutane-1-carboxylic acid)carbonyl cyclopentadienyl] [tricarbonyl] 168  
1-t-Butyl carbamate-3-(5-(1-pentylamine))cyclobutane-1-carboxylic acid methyl ester 162

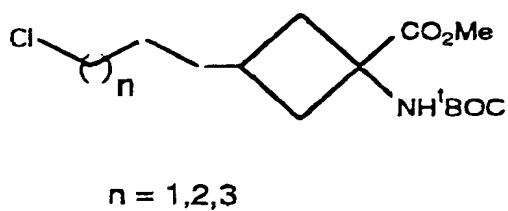
5 The above procedure for 144 is followed using 1-t-butyl carbamate-3-(5-(1-chloropentyl))cyclobutane-1-carboxylic acid methyl ester (126).

10 [99mTc] technetium, [3-(1-(5-pentaneamine))aminocyclobutane-1-carboxylic acid)carbonyl cyclopentadienyl] [tricarbonyl] 168

The above procedure for 150 is followed using 1-t-butyl carbamate-3-(5-(1-pentylamine))cyclobutane-1-carboxylic acid methyl ester (162) as the amino compound.

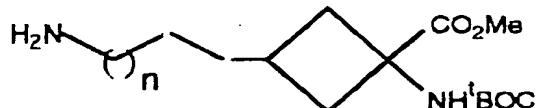
15

[99mTc] technetium, [3-(5-(1-pentaneamine))-1-aminocyclobutane-1-carboxylic acid)carbonyl cyclopentadienyl][tricarbonyl]

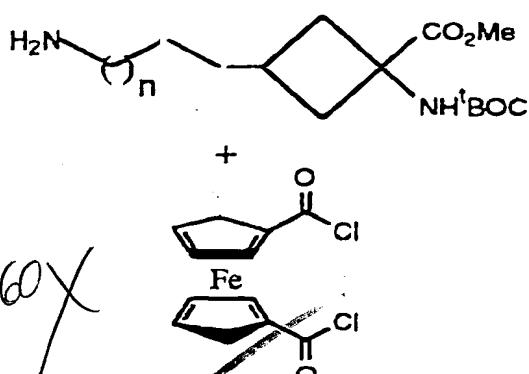


1.  $\text{NaN}_3$   
2.  $\text{NaBH}_4$

Step 105

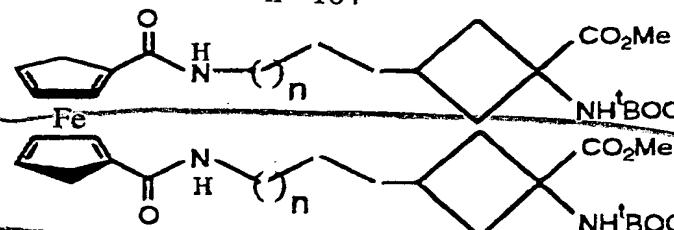


$n = 162$   
 $n = 163$   
 $n = 164$



$\text{Et}_3\text{N}$   
 $\text{CH}_2\text{Cl}_2$

Step 106



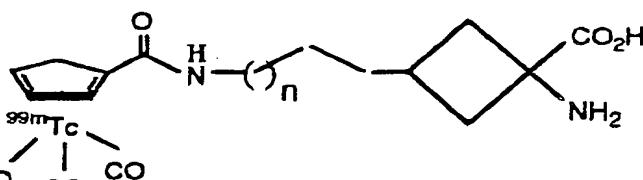
$n = 165$   
 $n = 166$   
 $n = 167$

1.  $\text{Mn}(\text{CO})_5\text{Br}$

$^{99\text{m}}\text{TcO}_4$

2. TFA

Step 107



$n = 168$   
 $n = 169$   
 $n = 170$

Example 27. Synthesis of [99mTc] technetium, [3-(1-(5-aminopent-1(E)-enyl))-1-aminocyclobutane-1-carboxylic acid)carbonyl cyclopentadienyl] [tricarbonyll 177.

1-t-Butyl carbamate-3-(1-(5-aminopent-1(E)-enyl))cyclobutane-1-carboxylic acid methyl ester 162.  
5

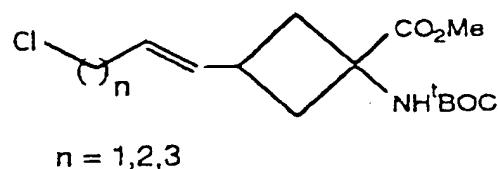
The above procedure for 144 is followed using 1-t-butyl carbamate-3-(1-(5-aminopent-1(E)-enyl))cyclobutane-1-carboxylic acid methyl ester (135).

[99mTc] Technetium, [3-(1-(5-aminopent-1(E)-enyl))-1-aminocyclobutane-1-carboxylic acid)carbonyl cyclopentadienyl] [tricarbonyl] 177  
10

The above procedure for 150 is followed using 1-t-butyl carbamate-3-(1-(5-aminopent-1(E)-enyl))-cyclobutane-1-carboxylic acid methyl ester 171 as the amino compound.  
15

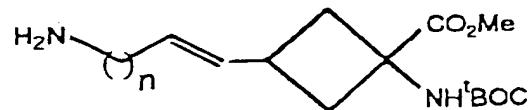
66  
67

[<sup>99m</sup>Tc] Technetium, [3-(1-(5-aminopent-1(E)-enyl))-1-aminocyclobutane-1-carboxylic acid)carbonyl cyclopentadienyl][tricarbonyl]

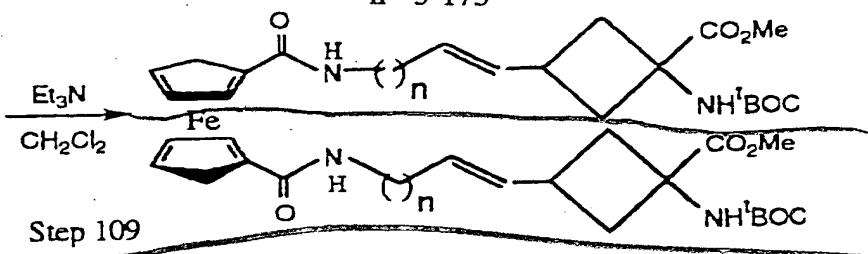
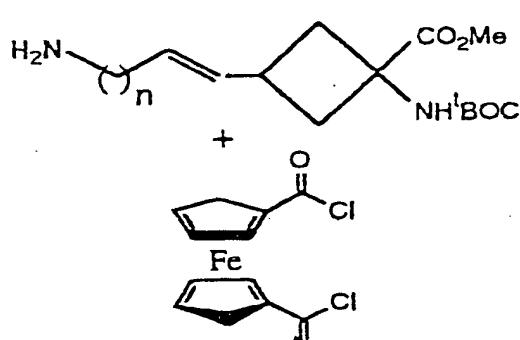


1.  $\text{NaN}_3$   
2.  $\text{NaBH}_4$

Step 108

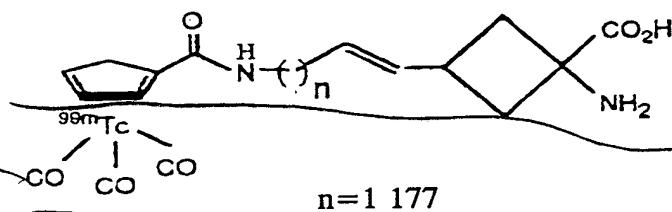


$n=1 \ 171$   
 $n=2 \ 172$   
 $n=3 \ 173$



$n=1 \ 174$   
 $n=2 \ 175$   
 $n=3 \ 176$

1.  $\text{Mn}(\text{CO})_5\text{Br}$   
2.  $^{99m}\text{TcO}_4$   
2. TFA  
Step 110



$n=1 \ 177$   
 $n=2 \ 178$   
 $n=3 \ 179$

TO660X

68  
6-7

Example 28.

Synthesis of [99mTc] Technetium, bis[3-(1-(5N-aminopent-1-ynyl)-6-hydrazinonicotinamide)-1-aminocyclobutane-1-carboxylic acid] 183

5      1-t-Butyl carbamate-3-(1-(5-aminopent-1ynyl))cyclobutane-1-carboxylic acid methyl ester (144) is added to a solution of succinimidyl-6-t-Boc-hydrazinopyridine-3-carboxylic acid and diisopropylethylamine in DMF. The mixture is stirred for 2 h, water is added and the mixture is extracted with ether. The t-Boc and methyl protecting groups are removed by stirring the crude 10 product with 5 ml of trifluoroacetic acid (TFA). The TFA is removed by rotary evaporation and the product (180) is purified by reverse phase HPLC.

15      The following procedure is used to radiolabel the HYNIC amino acid analogs with <sup>99m</sup>Tc. A solution of the Hynic amino acid 171, DMSO, 0.1 M acetate buffer pH 5.2 and <sup>99m</sup>Tc-glucoheptonate are vortexed briefly and then the mixture is allowed to stand for 1 h. The labeled compound 174 is purified by reverse phase HPLC.

20      Synthesis of [99mTc] technetium, bis[3-(1-(5N-aminopent-1(Z)-enyl)-6-hydrazinonicotinamide)-1-aminocyclobutane-1-carboxylic acid] 189

The above procedure for 183 is followed using 1-t-butyl carbamate-3-(1-(5-aminopent-1(Z)-enyl))cyclobutane-1-carboxylic acid methyl ester (153) as the amino compound.

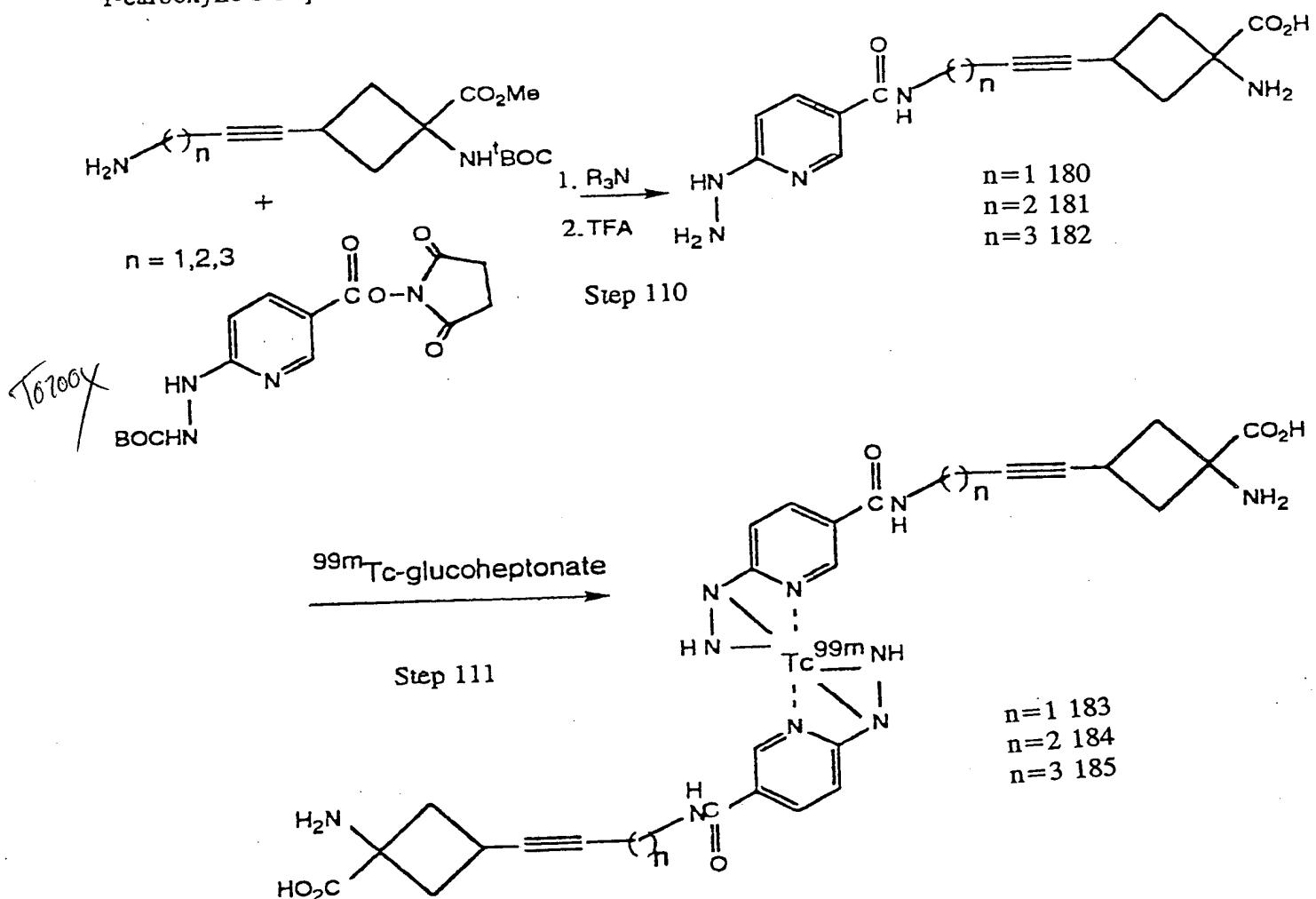
25      Synthesis of [99mTc] technetium, bis[3-(1-(5N-aminopentyl)-6-hydrazinonicotinamide)-1-aminocyclobutane-1-carboxylic acid] 195

The above procedure for 183 is followed using 1-t-butyl carbamate-3-(5-(1-pentylamine))cyclobutane-1-carboxylic acid methyl ester (153) as the amino compound.

30      Synthesis of [99mTc] technetium, bis[3-(1-(5N-aminopent-1(E)-enyl)-6-hydrazinonicotinamide)-1-aminocyclobutane-1-carboxylic acid] 201

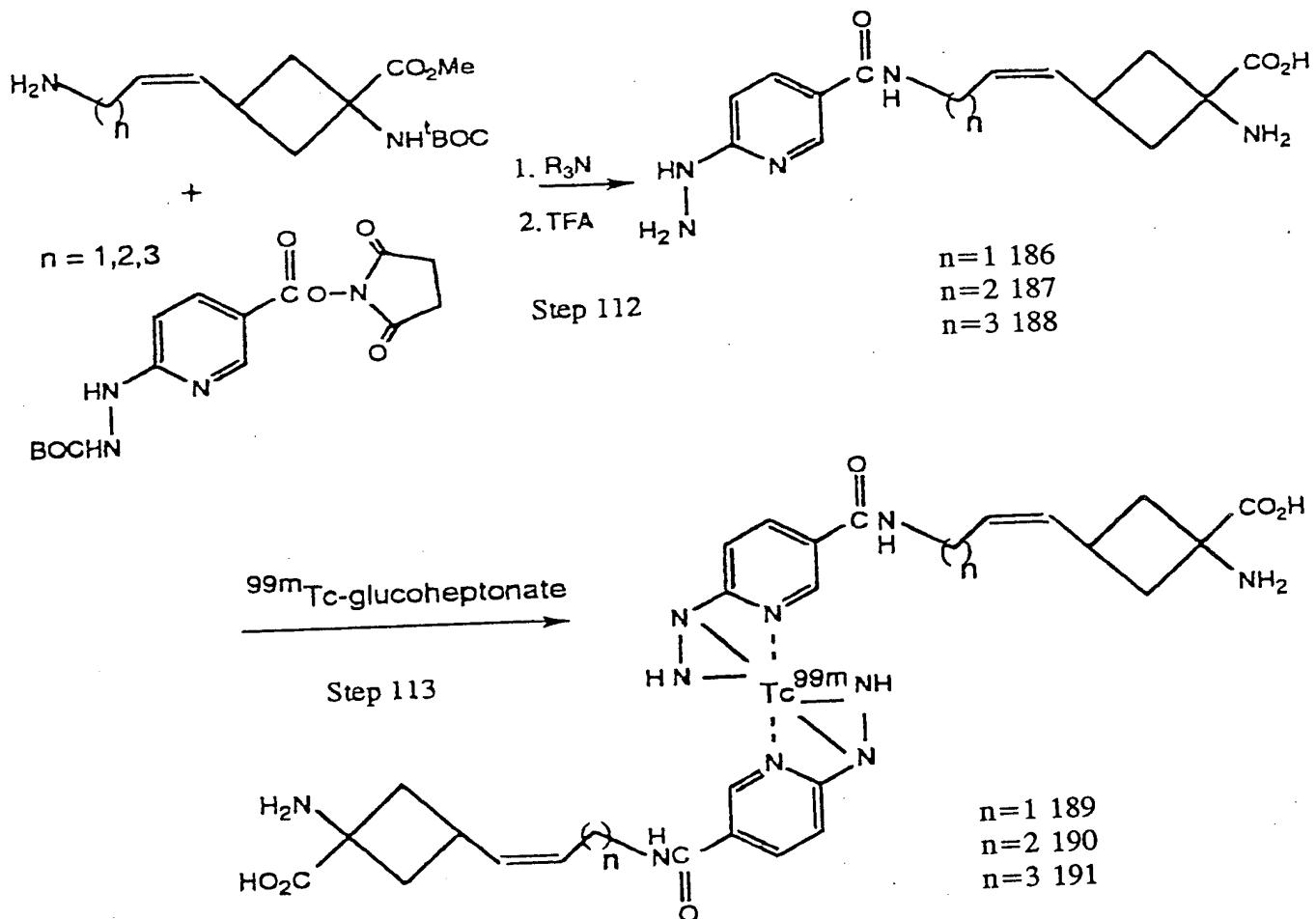
35      The above procedure for 183 is followed using 1-t-butyl carbamate-3-(1-(5-aminopent-1(E)-enyl))cyclobutane-1-carboxylic acid methyl ester (171) as the amino compound.

[99mTc]Technetium,bis[3-(1-(SN-aminopent-1-ynyl)-6-hydrazinonicoumarinamide)-1-aminocyclobutane-1-carboxylic acid ]



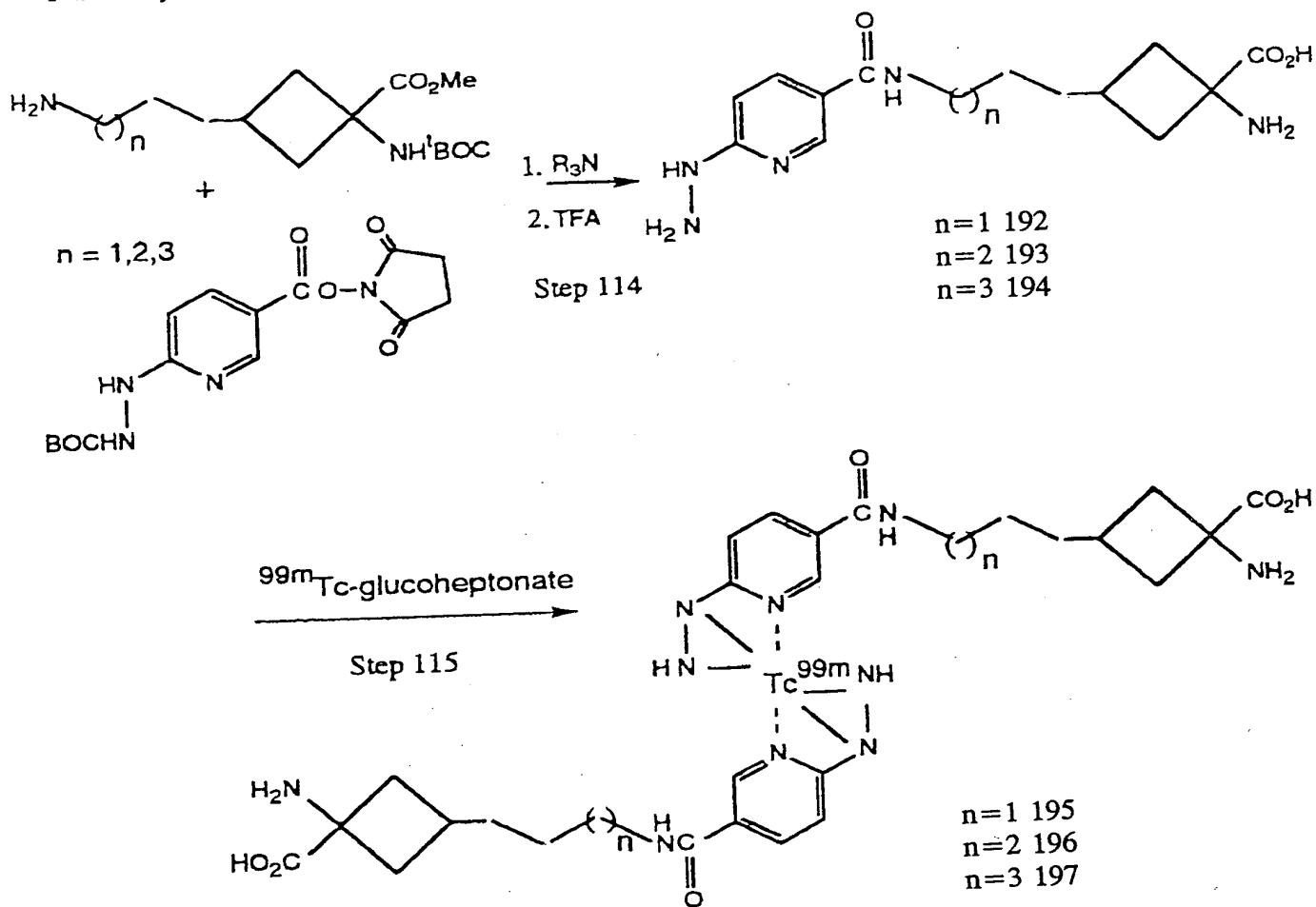
69° 70

[ $^{99m}\text{Tc}$ ] technetium, bis[3-(1-(5N-aminopent-1(Z)-enyl)-6-hydrazinonicotinamide)-1-aminocyclobutane-1-carboxylic acid]



70

[<sup>99m</sup>Tc] Technetium, bis[3-(1-(5N-aminopentyl)-6-hydrazinonicotinamide)-1-aminocyclobutane-1-carboxylic acid]



71  
 72

[99mTc] technetium, bis[3-(1-(5N-aminopent-1(E)-enyl)-6-hydrazinonicotinamide)-1-aminocyclobutane-1-carboxylic acid ]

